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<b>(21) International Application Number:</b> PCT/US96/01001 <b>(22) International Filing Date:</b> 24 January 1996 (24.01.96)  <b>(30) Priority Data:</b> 08/394,177      24 February 1995 (24.02.95)      US  <b>(71) Applicant:</b> THE GENERAL HOSPITAL CORPORATION [US/US]; 55 Fruit Street, Boston, MA 02114 (US).  <b>(72) Inventors:</b> SEED, Brian; Nine Hawthorne Place, No. 5J, Boston, MA 02114 (US). ROMEO, Charles; 45 Chester Road, Belmont, MA 02178 (US). KOLANUS, Waldemar; Gosswinstrasse 7, D-81245 München (DE).  <b>(74) Agent:</b> LECH, Karen, F.; Fish & Richardson P.C., 225 Franklin Street, Boston, MA 02110-2804 (US).		<b>(81) Designated States:</b> AU, CA, CZ, FI, HU, JP, KR, NO, NZ, RU, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>
<b>(54) Title:</b> REDIRECTION OF CELLULAR IMMUNITY BY PROTEIN-TYROSINE KINASE CHIMERAS  <b>(57) Abstract</b>  Disclosed is a method of directing a cellular response in a mammal by expressing in a cell of the mammal a chimeric receptor which causes the cells to specifically recognize and destroy an infective agent, a cell infected with an infective agent, a tumor or cancerous cell, or an autoimmune-generated cell. The chimeric receptor includes an extracellular portion which is capable of specifically recognizing and binding the target cell or target infective agent, and (b) an intracellular portion of a protein-tyrosine kinase which is capable of signalling the therapeutic cell to destroy a receptor-bound target cell or a receptor-bound target infective agent. Also disclosed are cells which express the chimeric receptors and DNA encoding the chimeric receptors.		

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REDIRECTION OF CELLULAR IMMUNITY BY  
PROTEIN-TYROSINE KINASE CHIMERAS

This invention was made with Government support  
5 under NIH grant AI27849. The government has certain  
rights in the invention.

The invention concerns functional protein-tyrosine  
kinase chimeras which are capable of redirecting immune  
system function. More particularly, it concerns the  
10 regulation of lymphocytes, macrophages, natural killer  
cells, or granulocytes by the expression in said cells of  
chimeras which cause the cells to respond to targets  
recognized by the chimeras. The invention also concerns  
functional protein-tyrosine kinase chimeras which are  
15 capable of directing therapeutic cells to specifically  
recognize and destroy either cells infected with a  
specific infective agent, the infective agent itself, a  
tumor cell, or an autoimmune-generated cell. More  
particularly, the invention relates to the production of  
20 protein-tyrosine kinase chimeras capable of directing  
cytotoxic T lymphocytes to specifically recognize and  
lyse cells expressing HIV envelope proteins. The  
invention therefore provides a novel anti-tumor therapy  
as well as a therapy for diseases such as AIDS (Acquired  
25 Immunodeficiency Syndrome) which are caused by the HIV  
virus.

Background of the Invention

T cell recognition of antigen through the T cell  
receptor is the basis of a range of immunological  
30 phenomena. The T cells direct what is called cell-  
mediated immunity. This involves the destruction by  
cells of the immune system of foreign tissues or infected  
cells. A variety of T cells exist, including "helper"  
and "suppressor" cells, which modulate the immune

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response, and cytotoxic (or "killer") cells, which can kill abnormal cells directly.

A T cell that recognizes and binds a unique antigen displayed on the surface of another cell becomes  
5 activated; it can then multiply, and, if it is a cytotoxic cell, it can kill the bound cell.

Autoimmune disease is characterized by production of either antibodies that react with host tissue or immune effector T cells that are autoreactive. In some  
10 instances, autoantibodies may arise by a normal T- and B-cell response activated by foreign substances or organisms that contain antigens that cross react with similar compounds in body tissues. Examples of clinically relevant autoantibodies are antibodies against  
15 acetylcholine receptors in myasthenia gravis; and anti-DNA, anti-erythrocyte, and anti-platelet antibodies in systemic lupus erythematosus.

#### **HIV and Immunopathogenesis**

In 1984 HIV was shown to be the etiologic agent of  
20 AIDS. Since that time the definition of AIDS has been revised a number of times with regard to what criteria should be included in the diagnosis. However, despite the fluctuation in diagnostic parameters, the simple common denominator of AIDS is the infection with HIV and  
25 subsequent development of persistent constitutional symptoms and AIDS defining diseases such as a secondary infections, neoplasms, and neurologic disease.  
Harrison's Principles of Internal Medicine, 12th ed., McGraw Hill (1991).

30 HIV is a human retrovirus of the lentivirus group. The four recognized human retroviruses belong to two distinct groups: the human T lymphotropic (or leukemia) retroviruses, HTLV-1 and HTLV-2, and the human immunodeficiency viruses, HIV-1 and HIV-2. The former

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are transforming viruses whereas the latter are cytopathic viruses.

HIV-1 has been identified as the most common cause of AIDS throughout the world. Sequence homology between  
5 HIV-2 and HIV-1 is about 40% with HIV-2 being more closely related to some members of a group of simian immunodeficiency viruses (SIV). See Curran et al., Science 329:1357-1359 (1985); Weiss et al., Nature 324:572-575 (1986).

10 HIV has the usual retroviral genes (env, gag, and pol) as well as six extra genes involved in the replication and other biologic activities of the virus. As stated previously, the common denominator of AIDS is a profound immunosuppression, predominantly of cell-  
15 mediated immunity. This immune suppression leads to a variety of opportunistic diseases, particularly certain infections and neoplasms.

The main cause of the immune defect in AIDS, has been identified as a quantitative and qualitative  
20 deficiency in the subset of thymus-derived (T) lymphocytes, the T4 population. This subset of cells is defined phenotypically by the presence of the CD4 surface molecule, which has been demonstrated to be the cellular receptor for HIV. Dalglish et al., Nature 312:763  
25 (1984). Although the T4 cell is the major cell type infected with HIV, essentially any human cell that expresses the CD4 molecule on its surface is capable of binding to and being infected with HIV.

Traditionally, CD4<sup>+</sup> T cells have been assigned the  
30 role of helper/inducer, indicating their function in providing an activating signal to B cells, or inducing T lymphocytes bearing the reciprocal CD8 marker to become cytotoxic/suppressor cells. Reinherz and Schlossman, Cell 19:821-827 (1980); Goldstein et al., Immunol. Rev.  
35 68:5-42, (1982).

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HIV binds specifically and with high affinity, via a stretch of amino acids in the viral envelope (gp120), to a portion of the V1 region of the CD4 molecule located near its N-terminus. Following binding, the virus fuses  
5 with the target cell membrane and is internalized. Once internalized it uses the enzyme reverse transcriptase to transcribe its genomic RNA to DNA, which is integrated into the cellular DNA where it exists for the life of the cell as a "provirus."

10 The provirus may remain latent or be activated to transcribe mRNA and genomic RNA, leading to protein synthesis, assembly, new virion formation, and budding of virus from the cell surface. Although the precise mechanism by which the virus induces cell death has not  
15 been established, it is felt that the major mechanism is massive viral budding from the cell surface, leading to disruption of the plasma membrane and resulting osmotic disequilibrium.

During the course of the infection, the host  
20 organism develops antibodies against viral proteins, including the major envelope glycoproteins gp120 and gp41. Despite this humoral immunity, the disease progresses, resulting in a lethal immunosuppression characterized by multiple opportunistic infections,  
25 parasitemia, dementia and death. The failure of the host anti-viral antibodies to arrest the progression of the disease represents one of the most vexing and alarming aspects of the infection, and augurs poorly for vaccination efforts based upon conventional approaches.

30 Two factors may play a role in the efficacy of the humoral response to immunodeficiency viruses. First, like other RNA viruses (and like retroviruses in particular), the immunodeficiency viruses show a high mutation rate in response to host immune surveillance.  
35 Second, the envelope glycoproteins themselves are heavily

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glycosylated molecules presenting few epitopes suitable for high affinity antibody binding. The poorly antigenic target which the viral envelope presents, allows the host little opportunity for restricting viral infection by specific antibody production.

Cells infected by the HIV virus express the gp120 glycoprotein on their surface. Gp120 mediates fusion events among CD4<sup>+</sup> cells via a reaction similar to that by which the virus enters the uninfected cells, leading to the formation of short-lived multinucleated giant cells. Syncytium formation is dependent on a direct interaction of the gp120 envelope glycoprotein with the CD4 protein. Dalglish et al., supra; Klatzman et al., Nature 312:763 (1984); McDougal et al., Science 231:382 (1986); Sodroski et al., Nature 322:470 (1986); Lifson et al., Nature, 323:725 (1986); Sodroski et al., Nature 321:412 (1986).

Evidence that the CD4-gp120 binding is responsible for viral infection of cells bearing the CD4 antigen includes the finding that a specific complex is formed between gp120 and CD4 (McDougal et al., supra). Other investigators have shown that the cell lines, which were noninfective for HIV, were converted to infectable cell lines following transfection and expression of the human CD4 cDNA gene. Maddon et al., Cell 46:333-348 (1986).

Therapeutic programs based on soluble CD4 as a passive agent to interfere with viral adsorption and syncytium-mediated cellular transmission have been proposed and successfully demonstrated in vitro by a number of groups (Deen et al., Nature 332:82-84 (1988); Fisher et al., Nature 331:76-78 (1988); Hussey et al., Nature 331:78-81 (1988); Smith et al., Science 238:1704-1707 (1987); Trauneker et al., Nature 331:84-86 (1988)); and CD4 immunoglobulin fusion proteins with extended half-lives and modest biological activity have subsequently been developed (Capon et al., Nature

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337:525-531 (1989); Traunecker et al. Nature 339, 68-70 (1989); Byrn et al., Nature 344:667-670 (1990); Zettlmeissl et al., DNA Cell Biol. 9:347-353 (1990)). Although CD4 immunotoxin conjugates or fusion proteins show potent cytotoxicity for infected cells in vitro (Chaudhary et al., Nature 335:369-372 (1988); Till et al., Science 242:1166-1168 (1988)), the latency of the immunodeficiency syndrome makes it unlikely that any single-treatment therapy will be effective in eliminating viral burden, and the antigenicity of foreign fusion proteins is likely to limit their acceptability in treatments requiring repetitive dosing. Trials with monkeys affected with SIV have shown that soluble CD4, if administered to animals without marked CD4 cytopenia, can reduce SIV titer and improve in vitro measures of myeloid potential (Watanabe et al., Nature 337:267-270 (1989)). However a prompt viral reemergence was observed after treatment was discontinued, suggesting that lifelong administration might be necessary to prevent progressive immune system debilitation.

#### Cell Surface Receptor-Associated Protein-Tyrosine Kinases

The initial impetus for engagement of cellular effector programs in the immune system is often cell recognition of clustered ligands. Among the receptors known to transmit activating signals upon aggregation are the B cell and T cell antigen receptors (DeFranco, Eur. J. Biochem. 210:381-388 (1992); Weiss, Annu. Rev. Genet. 25:487-510 (1991)), members of the IgG and IgE Fc receptor families (Fanger et al., Immunol. Today 10:92-99 (1989); Ravetch and Kinet, Annu. Rev. Immunol. 9:457-492 (1991)) and a number of accessory receptors, including CD2, CD4, CD8, and CD28 in T cells (Yokoyama and Shevach, Year Immunol. 4:110-146 (1989)), CD19, CD20, CD21, and CD40 in B cells (Clark and Ledbetter, Adv. Cancer Res.



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52:81-149 (1989)), and CD44, CD45, and CD58 in monocytes (Webb et al., Science 249:1295-1297 (1990)). In addition, a large number of phospholipid linked proteins promote cellular activation in an antigen  
5 receptor-dependent manner when crosslinked on the surface of T cells (Balk and Terhorst, Immunol. Ser. 45:411-416 (1989); Kroczeck et al., Nature 322:181-184 (1986); Yeh et al., J. Immunol. 138:91-97 (1987); Yokoyama and Shevach, Year Immunol. 4:110-146 (1989)).

10 At present it is not clear how a simple physical event, aggregation, results in a clearly distinguished physiological signal. Engagement of cellular effector programs mediated by the T cell and B cell antigen  
15 receptors, and various forms of Fc receptor, can be mimicked by crosslinking of chimeric proteins bearing the intracellular domains of individual chains of the receptor complexes (Irving and Weiss, Cell 64:891-901 (1991); Kolanus et al., EMBO J. 11:4861-4868 (1992);  
20 Letourneur and Klausner, Proc. Natl. Acad. Sci. USA 88:8905-8909 (1991); Letourneur and Klausner, Science 255:79-82 (1992); Romeo and Seed, Cell 64:1037-1046 (1991); Wegener et al., Cell 68:83-95 (1992)). The minimal effective trigger element appears to require a phylogenetically conserved (Reth, Nature 338:383-384  
25 (1989)) peptide sequence containing two tyrosine residues separated by 10 or 11 residues and embedded in a hydrophilic, typically acidic context (Romeo et al., Cell 68:889-897 (1992); Irving et al., J. Exp. Med. 177, 1093-1103 (1993)). Clustering of receptors bearing this  
30 element initiates an activation cascade for which protein tyrosine kinase (PTK) activity appears to be essential; PTK inhibitors block both early events in B and T cell activation such as calcium mobilization and the later sequelae of cytokine release and cellular proliferation  
35 (June et al., J. Immunol. 144:1591-1599 (1990); Lane et

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al., J. Immunol. 146:715-722 (1991); Mustelin et al.,  
Science 247:1584-1587 (1990); Stanley et al., J. Immunol.  
145:2189-2198 (1990)). Although the more distal  
consequences of receptor activation differ according to  
5 cell type, the early events are strikingly similar among  
cells from disparate hematopoietic lineages. For example  
the rapid increases in PTK activity observed following  
crosslinking of the B cell antigen receptor (Gold et al.,  
Nature 345:810-813 (1990); Campbell and Sefton, EMBO J.  
10 9:2125-2131 (1990)), the T cell antigen receptor (June et  
al., Proc. Natl. Acad. Sci. USA 87:7722-7726 (1990); June  
et al., J. Immunol. 144:1591-1599 (1990)) and the high  
affinity IgE receptor (Eiseman and Bolen, Nature 355:78-  
80 (1992); Li et al., Mol. Cell. Biol. 12:3176-3182  
15 (1992)) all have among their early phosphorylation  
targets the  $\gamma$  isoform of phosphatidylinositol-specific  
phospholipase C (Carter et al., Proc. Natl. Acad. Sci.  
USA 88:2745-2749 (1991); Li et al., Mol. Cell Biol.  
12:3176-3182 (1992); Park et al., J. Biol. Chem.  
20 266:24237-24240 (1991); Park et al., Proc. Natl. Acad.  
Sci. USA 88:5453-5456 (1991); Secrist et al., J. Biol.  
Chem. 266:12135-12139 (1991); Weiss et al., Annu. Rev.  
Genet. 25:487-510 (1991)), which is directly activated by  
tyrosine phosphorylation (Nishibe et al., Science  
25 250:1253-1256 (1990)).

The PTK activities known thus far to associate  
with cell surface receptors fall in two classes: those  
belonging to the family of Src proto-oncogene-related  
kinases and those related to the recently characterized  
30 Syk kinase. Among the former, the Fyn kinase has been  
shown to associate with the T cell receptor (Gassmann et  
al., Eur. J. Immunol. 22:283-286 (1992); Samelson et al.,  
Proc. Natl. Acad. Sci. USA 87:4358-4362 (1990)), the Lyn,  
Fyn, Blk, and Lck kinases have been reported to associate  
35 with the B cell IgM receptor, (Burkhardt et al., Proc.

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Natl. Acad. Sci. USA 88:7410-7414 (1991); Campbell and Sefton, Mol. Cell. Biol. 12:2315-2321 (1992); Yamanashi et al., Science 251:192-194 (1991)), and the Lyn and Yes kinases have been shown to associate with the high  
5 affinity IgE receptor (Eiseman and Bolen, Nature 355:78-80 (1992); Hutchcroft et al., Proc. Natl. Acad. Sci. USA 89:9107-9111 (1992); Hutchcroft et al., J. Biol. Chem. 267:8613-8619 (1992)). The mechanism of the observed  
10 preliminary data suggest that the intracellular domains of receptor complex chains may physically associate with Src family kinases (Clark et al., Science 258:123-126 (1992); Timson Gauen et al., Mol. Cell. Biol. 12:5438-5446 (1992)). At present it is not clear whether these  
15 associations are direct or indirect.

To date, the most compelling evidence for the importance of Src family kinases in cell activation has been developed from the study of the Fyn and Lck kinases in T cells. Overexpression of Fyn in transgenic mice  
20 leads to an antigen hyperresponsive phenotype in the resulting T cells, while overexpression of a catalytically inactive form blocks T cell receptor mediated proliferation (Cooke et al., Cell 65:281-291 (1991)). Thymic T cells isolated from mutant mice  
25 lacking Fyn kinase activity show a profound defect in the ability to mount a proliferative response in response to treatment with a combination of phorbol ester plus either anti-CD3 antibody or Concanavalin A (Appleby et al., Cell 70:751-763 (1992); Stein et al., Cell 70:741-750 (1992)).  
30 Splenic T cells isolated from such mice show a less severe, but substantial, attenuation of the cell activation response (Appleby et al., Cell 70:751-763 (1992); Stein et al., Cell 70:741-750 (1992)).

In T cells the Lck kinase associates indirectly  
35 with the TCR through the CD4 and CD8 coreceptors (Rudd et

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al., Proc. Natl. Acad. Sci. USA 85:5190-5194 (1988); Shaw et al., Cell 59:627-636 (1989); Turner et al., Cell 60:755-765 (1990); Veillette et al., Cell 55:301-308 (1988)). Overexpression of Lck in an antigen-responsive  
5 cell line potentiates receptor sensitivity in similar fashion to that seen with Fyn (Abraham and Veillette, Mol. Cell. Biol. 10:5197-5206 (1990); Davidson et al., J. Exp. Med. 175:1483-1492 (1982); Luo and Sefton, Mol. Cell. Biol. 12:4724-4732 (1992)). In a CD4-dependent  
10 murine T cell hybridoma model, reconstitution of antigen-specific helper function could be achieved only with CD4 molecules which were capable of interacting with Lck (Glaichenhaus et al., Cell 64:511-520 (1991)).

However the strongest evidence for the direct  
15 participation of the Lck kinase in antigen receptor-mediated signalling comes from studies of mutant cell lines which lack Lck. Two such lines have been studied, one derived from the Jurkat human T cell leukemia line (Goldsmith and Weiss, Proc. Natl. Acad. Sci. USA 84:6879-6883 (1987); Straus and Weiss, Cell 70:585-593 (1992)) and the other from the murine cytotoxic T cell clone CTLL-2 (Karnitz et al., Mol. Cell. Biol. 12:4521-4530 (1992)). Both Lck-negative mutant  
20 lines are defective in TCR mediated signalling, and complementation of either mutant line by transfection with an Lck expression plasmid restores responsiveness to TCR crosslinking stimuli (Karnitz et al., Mol. Cell. Biol. 12:4521-4530 (1992); Straus and Weiss, Cell 70:585-593 (1992)).

30 Recently members of a new family of tyrosine kinases, initially represented by the closely related or identical kinases Syk (Taniguchi et al., J. Biol. Chem. 266:15790-15796 (1991)) and PTK 72 (Zioncheck et al., J. Biol. Chem. 261:15637-15643 (1986); Zioncheck et al., J. Biol. Chem. 263:19195-19202 (1988)), have been to shown  
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to associate with cell surface receptors. Although PTK 72 and Syk have not been definitively proven to be identical, they share a common tissue distribution (thymus and spleen), molecular mass, and lability to proteolysis. PTK 72 has been shown to associate with the B cell IgM receptor (Hutchcroft et al., Proc. Natl. Acad. Sci. USA 89:9107-9111 (1992); Hutchcroft et al., J. Biol. Chem. 267:8613-8619 (1992)) and to be phosphorylated upon crosslinking of the receptor with anti-IgM (Hutchcroft et al., J. Biol. Chem. 266:14846-14849 (1991)). A concomitant activation of the enzyme, as measured by both autophosphorylation and phosphorylation of an exogenous protein fragment, was demonstrated following surface IgM crosslinking (Hutchcroft et al., Proc. Natl. Acad. Sci. USA 89:9107-9111 (1992); Hutchcroft et al., J. Biol. Chem. 267:8613-8619 (1992)). PTK 72 is also found associated with the high affinity IgE receptor in a rat basophilic leukemia cell line (Hutchcroft et al., Proc. Natl. Acad. Sci. USA 89:9107-9111 (1992); Hutchcroft et al., J. Biol. Chem. 267:8613-8619 (1992)).

A second member of the Syk family, ZAP-70, has been shown to be a PTK associating with the zeta chain of the T cell receptor following receptor crosslinking (Chan et al., Proc. Natl. Acad. Sci. USA 88:9166-9170 (1991)). Although expression in COS cells of ZAP-70, Fyn or Lck leads to modest increases in total cell tyrosine phosphate, coexpression of ZAP-70 and either Lck or Fyn leads to a dramatic increase in net tyrosine phosphorylation (Chan et al., Cell 71:649-662 (1992)). If a CD8-zeta chain chimera is also present, the chimera becomes phosphorylated and ZAP-70 is found associated with it (Chan et al., Cell 71:649-662 (1992)). At present it is not clear whether ZAP-70 activates the Src family kinases and/or vice versa, nor why coexpression of kinases in COS cells should lead to an apparent

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constitutive activation. Nonetheless the active association of ZAP-70 with crosslinked TCR suggests a role for this PTK in the propagation of the receptor response.

5           Unlike the Src family kinases, Syk and ZAP-70 bear two SH2 domains and no N-terminal myristoylation site (Taniguchi et al., J. Biol. Chem. 266:15790-15796 (1991); Chan et al., Cell 71:649-662 (1992)). A natural expectation for the mechanism of kinase-receptor  
10 association is that the two SH2 domains bind the two tyrosines of the antigen receptor trigger motifs once they are phosphorylated. However, at present this remains merely a hypothesis.

#### Summary of the Invention

15           The present invention demonstrates the feasibility of creating chimeras between the intracellular domain of a protein-tyrosine kinase molecule and an extracellular domain which is capable of fulfilling the task of target recognition. In particular, clustering of chimeras  
20 bearing Syk or ZAP-70 kinase sequences triggers calcium mobilization. Aggregation of Syk chimera alone, or coaggregation of chimeras bearing Fyn or Lck and ZAP-70 kinases, suffices to initiate cytolytic effector function. Such effector function facilitates the  
25 specific recognition and destruction of undesirable target cells, for example, pathogens, pathogen-infected cells, tumor cells, or autoimmune cells.

          Any number of useful chimeric molecules according to the invention may be constructed. For example, the  
30 formation of chimeras consisting of the intracellular portion of a protein-tyrosine kinase joined to the extracellular portion of a suitably engineered antibody molecule allows the target recognition potential of an immune system cell to be specifically redirected to the

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antigen recognized by the extracellular antibody portion. Thus with an antibody portion capable of recognizing some determinant on the surface of a pathogen, immune system cells armed with the chimera would respond to the presence of the pathogen with the effector program appropriate to their lineage, e.g., helper T lymphocytes would respond by cytotoxic activity against the target, and B lymphocytes would be activated to synthesize antibody. Macrophages and granulocytes would carry out their effector programs, including cytokine release, phagocytosis, and reactive oxygen generation. Similarly, with an antibody portion capable of recognizing tumor cells, the immune system response to the tumor would be beneficially elevated. With an antibody capable of recognizing immune cells having an inappropriate reactivity with self determinants, the autoreactive cells could be selectively targeted for destruction.

Although these examples draw on the use of antibody chimeras as a convenient expository tool, the invention is not limited in scope to antibody chimeras, and indeed, the use of specific nonantibody extracellular domains may have important advantages. For example with an extracellular portion that is the receptor for a virus, bacterium, or parasite, cells armed with the chimeras would specifically target cells expressing the viral, bacterial or parasitic determinants. The advantage of this approach over the use of antibodies is that the native receptor for pathogen may have uniquely high selectivity or affinity for the pathogen, allowing a greater degree of precision in the resulting immune response. Similarly, to delete immune system cells which inappropriately react with a self antigen, it may suffice to join the antigen (either as an intact protein, in the case of B cell depletion therapies, or as MHC complex, in the case of T cell depletion therapies) to intracellular

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protein-tyrosine kinase chains, and thereby affect the specific targeting of the cells inappropriately responding to self determinants.

Another use of the chimeras is the control of cell populations in vivo subsequent to other forms of genetic engineering. For example, the use of tumor infiltrating lymphocytes or natural killer cells to carry cytotoxic principles to the site of tumors has been proposed. The present invention provides a convenient means to regulate the numbers and activity of such lymphocytes and cells without removing them from the body of the patient for amplification in vitro. Thus, because the intracellular domains of the chimeric receptors mediate the proliferative responses of the cells, the coordination of the extracellular domains by a variety of aggregating stimuli specific for the extracellular domains (e.g., an antibody specific for the extracellular domain) will result in proliferation of the cells bearing the chimeras.

Although the specific embodiments of the present invention comprise chimeras between the Syk or Syk and Src families of protein-tyrosine kinases, any tyrosine kinase having a similar function to these molecules could be used for the purposes disclosed here. The distinguishing features of desirable immune cell trigger molecules comprise the ability to be expressed autonomously, the ability to be fused to an extracellular domain (directly or indirectly through a transmembrane domain) such that the resultant chimera is present on the surface of a therapeutic cell, and the ability to initiate cellular effector programs upon aggregation secondary to encounter with a target ligand.

At present the most convenient method for delivery of the chimeras to immune system cells is through some form of genetic therapy. However, reconstituting immune



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system cells with chimeric receptors by mixture of the cells with suitably solubilized purified chimeric protein would also result in the formation of an engineered cell population capable of responding to the targets

5 recognized by the extracellular domain of the chimeras. Similar approaches have been used, for example, to introduce the intact HIV receptor, CD4, into erythrocytes for therapeutic purposes. In this case the engineered cell population would not be capable of self renewal.

10 The present invention relates to functional simplified protein-tyrosine kinase chimeras which are capable of redirecting immune system function. More particularly, it relates to the regulation of lymphocytes, macrophages, natural killer cells, or  
15 granulocytes by the expression in said cells of chimeras which cause the cells to respond to targets recognized by the chimeras. The invention also relates to a method of directing cellular responses to an infective agent, a tumor or cancerous cell, or an autoimmune-generated cell.  
20 The method for directing the cellular response in a mammal comprises administering an effective amount of therapeutic cells to said mammal, said cells being capable of recognizing and destroying said infective agent, tumor, cancer cell, or autoimmune-generated cell.  
25 The cellular response may be mediated by a single chimera or may be the result of cooperation between multiple chimeras (for example, a set of two or more chimeras, one of which includes a CD28 intracellular domain).

In another embodiment, the method of directing a  
30 cellular response to an infective agent comprises administering therapeutic cells capable of recognizing and destroying said agent, wherein the agent is a specific virus, bacteria, protozoa, or fungi. Even more specifically, the method is directed against agents such  
35 as HIV and Pneumocystis carinii.

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To treat an HIV infection, an effective amount of chimeric-receptor expression cytotoxic T lymphocytes are administered to a patient; the lymphocytes are capable of specifically recognizing and lysing cells infected with  
5 HIV as well as circulating virus.

Thus, in one embodiment, there is provided according to the invention a method for directing cellular response to HIV infected cells, comprising administering to a patient an effective amount of  
10 cytotoxic T lymphocytes which are capable of specifically recognizing and lysing cells infected with HIV.

In yet another embodiment is provided the chimeric receptor proteins which direct the cytotoxic T lymphocytes to recognize and lyse the HIV-infected cell.  
15 Yet another embodiment of the invention comprises host cells transformed with a vector comprising the chimeric receptors.

A number of methods for constructing and expressing chimeric immune receptors as well as a variety  
20 of therapeutic uses thereof are explained in detail in U.S.S.N. 07/847,566 and 07/665,961, hereby incorporated by reference.

These and other non-limiting embodiments of the present invention will be apparent to those of skill from  
25 the following detailed description of the invention.

In the following detailed description, reference will be made to various methodologies known to those of skill in the art of molecular biology and immunology. Publications and other materials setting forth such known  
30 methodologies to which reference is made are incorporated herein by reference in their entireties as though set forth in full.

Standard reference works setting forth the general principles of recombinant DNA technology include Watson  
35 et al., Molecular Biology of the Gene, volumes I and II,

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the Benjamin/Cummings Publishing Company, Inc., publisher, Menlo Park, CA (1987); Darnell et al., Molecular Cell Biology, Scientific American Books, Inc., publisher, New York, N.Y. (1986); Lewin, Genes II, John Wiley & Sons, publishers, New York, N.Y. (1985); Old et al., Principles of Gene Manipulation: An Introduction to Genetic Engineering, 2nd edition, University of California Press, publisher, Berkeley, CA (1981); Maniatis et al., Molecular Cloning: A Laboratory Manual, 2nd ed. Cold Spring Harbor Laboratory, publisher, Cold Spring Harbor, NY (1989); and Ausubel et al., Current Protocols in Molecular Biology, Wiley Press, New York, NY (1989).

#### Definitions

By "cloning" is meant the use of in vitro recombination techniques to insert a particular gene or other DNA sequence into a vector molecule. In order to successfully clone a desired gene, it is necessary to employ methods for generating DNA fragments for joining the fragments to vector molecules, for introducing the composite DNA molecule into a host cell in which it can replicate, and for selecting the clone having the target gene from amongst the recipient host cells.

By "cDNA" is meant complementary or copy DNA produced from an RNA template by the action of RNA-dependent DNA polymerase (reverse transcriptase). Thus a "cDNA clone" means a duplex DNA sequence complementary to an RNA molecule of interest, carried in a cloning vector.

By "cDNA library" is meant a collection of recombinant DNA molecules containing cDNA inserts which comprise DNA copies of mRNA being expressed by the cell at the time the cDNA library was made. Such a cDNA library may be prepared by methods known to those of skill, and described, for example, in Maniatis et al.,

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Molecular Cloning: A Laboratory Manual, supra.

Generally, RNA is first isolated from the cells of an organism from whose genome it is desired to clone a particular gene. Preferred for the purpose of the  
5 present invention are mammalian, and particularly human, lymphocytic cell lines. A presently preferred vector for this purpose is the vaccinia virus WR strain.

By "vector" is meant a DNA molecule derived, e.g., from a plasmid, bacteriophage, or mammalian or insect  
10 virus, into which fragments of DNA may be inserted or cloned. A vector will contain one or more unique restriction sites and may be capable of autonomous replication in a defined host or vehicle organism such that the cloned sequence is reproducible. Thus, by "DNA  
15 expression vector" is meant any autonomous element capable of directing the synthesis of a recombinant peptide. Such DNA expression vectors include bacterial plasmids and phages and mammalian and insect plasmids and viruses.

20 By "substantially pure" is meant a compound, e.g., a protein, a polypeptide, or an antibody, that is substantially free of the components that naturally accompany it. Generally, a compound is substantially pure when at least 60%, more preferably at least 75%, and  
25 most preferably at least 90% of the total material in a sample is the compound of interest. Purity can be measured by any appropriate method, e.g., column chromatography, polyacrylamide gel electrophoresis, or HPLC analysis. In the context of a nucleic acid,  
30 "substantially pure" means a nucleic acid sequence, segment, or fragment that is not immediately contiguous with (i.e., covalently linked to) both of the coding sequences with which it is immediately contiguous (i.e., one at the 5' end and one at the 3' end) in the naturally

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occurring genome of the organism from which the DNA of the invention is derived.

By "functional derivative" is meant the "fragments," "variants," "analogues," or "chemical derivatives" of a molecule. A "fragment" of a molecule, 5 such as any of the cDNA sequences of the present invention, is meant to refer to any nucleotide subset of the molecule. A "variant" of such molecule is meant to refer to a naturally occurring molecule substantially 10 similar to either the entire molecule, or a fragment thereof. An "analog" of a molecule is meant to refer to a non-natural molecule substantially similar to either the entire molecule or a fragment thereof. A molecule is said to be "substantially similar" to another molecule if 15 the sequence of amino acids in both molecules is substantially the same. In particular, a "substantially similar" amino acid sequence is one that exhibits at least 50%, preferably 85%, and most preferably 95% amino acid sequence identity to the natural or reference 20 sequence and/or one that differs from the natural or reference amino acid sequence only by conservative amino acid substitutions. Substantially similar amino acid molecules will possess a similar biological activity. Thus, provided that two molecules possess a similar 25 activity, they are considered variants as that term is used herein even if one of the molecules contains additional or fewer amino acid residues not found in the other, or if the sequence of amino acid residues is not identical. As used herein, a molecule is said to be a 30 "chemical derivative" of another molecule when it contains additional chemical moieties not normally a part of the molecule. Such moieties may improve the molecule's solubility, absorption, biological half life, etc. The moieties may alternatively decrease the 35 toxicity of the molecule, eliminate or attenuate any

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undesirable side effect of the molecule, etc. Moieties capable of mediating such effects are disclosed, for example, in Remington's Pharmaceutical Sciences, 16th ed., Mack Publishing Co., Easton, PA. (1980).

5           Similarly, a "functional derivative" of a receptor chimera gene of the present invention is meant to include "fragments," "variants," or "analogues" of the gene, which may be "substantially similar" in nucleotide sequence, and which encode a molecule possessing similar  
10 activity to a protein-tyrosine kinase chimera. "Substantially similar" nucleic acids encode substantially similar amino acid sequences (as defined above) and also may include any nucleic acid sequence capable of hybridizing to the natural or reference  
15 nucleic acid sequence under appropriate hybridization conditions (see, for example, Ausubel et al., Current Protocols in Molecular Biology, Wiley Press, New York, NY (1989) for appropriate hybridization stringency conditions).

20           Thus, as used herein, a protein-tyrosine kinase chimera protein is also meant to include any functional derivative, fragments, variants, analogues, or chemical derivatives which may be substantially similar to the "wild-type" chimera and which possess similar activity  
25 (i.e., most preferably, 90%, more preferably, 70%, preferably 40%, or at least 10% of the wild-type receptor chimera's activity). The activity of a functional chimeric receptor derivative includes specific binding (with its extracellular portion) to a targeted agent or  
30 cell and resultant destruction (directed by its intracellular portion) of that agent or cell; such activity may be tested, e.g., using any of the assays described herein.

          A DNA sequence encoding the chimera of the present  
35 invention, or its functional derivatives, may be

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recombined with vector DNA in accordance with conventional techniques, including blunt-ended or staggered-ended termini for ligation, restriction enzyme digestion to provide appropriate termini, filling in of cohesive ends as appropriate, alkaline phosphatase treatment to avoid undesirable joining, and ligation with appropriate ligases. Techniques for such manipulations are disclosed by Maniatis et al., supra, and are well known in the art.

10 A nucleic acid molecule, such as DNA, is said to be "capable of expressing" a polypeptide if it contains nucleotide sequences which contain transcriptional and translational regulatory information, and such sequences are "operably linked" to nucleotide sequences which  
15 encode the polypeptide. An operable linkage is a linkage in which the regulatory DNA sequences and the DNA sequence sought to be expressed are connected in such a way as to permit gene expression. The precise nature of the regulatory regions needed for gene expression may  
20 vary from organism to organism, but shall in general include a promoter region which, in prokaryotes, contains both the promoter (which directs the initiation of RNA transcription) as well as the DNA sequences which, when transcribed into RNA, will signal the initiation of  
25 protein synthesis. Such regions will normally include those 5'-non-coding sequences involved with initiation of transcription and translation, such as the TATA box, capping sequence, CAAT sequence, and the like.

If desired, the non-coding region 3' to the gene  
30 sequence coding for the protein may be obtained by the above-described methods. This region may be retained for its transcriptional termination regulatory sequences, such as termination and polyadenylation. Thus, by retaining the 3'-region naturally contiguous to the DNA  
35 sequence coding for the protein, the transcriptional

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termination signals may be provided. Where the transcriptional termination signals are not satisfactorily functional in the expression host cell, then a 3' region functional in the host cell may be substituted.

Two DNA sequences (such as a promoter region sequence and a protein-tyrosine kinase chimera-encoding sequence) are said to be operably linked if the nature of the linkage between the two DNA sequences does not (1) result in the introduction of a frame-shift mutation, (2) interfere with the ability of the promoter region sequence to direct the transcription of the receptor chimera gene sequence, or (3) interfere with the ability of the receptor chimera gene sequence to be transcribed by the promoter region sequence. A promoter region would be operably linked to a DNA sequence if the promoter were capable of effecting transcription of that DNA sequence. Thus, to express the protein, transcriptional and translational signals recognized by an appropriate host are necessary.

The present invention encompasses the expression of a protein-tyrosine kinase chimera protein (or a functional derivative thereof) in either prokaryotic or eukaryotic cells, although eukaryotic (and, particularly, human lymphocyte) expression is preferred.

Antibodies according to the present invention may be prepared by any of a variety of methods. For example, cells expressing the receptor chimera protein, or a functional derivative thereof, can be administered to an animal in order to induce the production of sera containing polyclonal antibodies that are capable of binding the chimera.

In a preferred method, antibodies according to the present invention are monoclonal antibodies. Such monoclonal antibodies can be prepared using hybridoma



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technology (Kohler et al., Nature 256:495 (1975); Kohler et al., Eur. J. Immunol. 6:511 (1976); Kohler et al., Eur. J. Immunol. 6:292 (1976); Hammerling et al., In: Monoclonal Antibodies and T-Cell Hybridomas, Elsevier, N.Y., pp. 563-684 (1981)). In general, such procedures involve immunizing an animal with the chimera antigen. The splenocytes of such animals are extracted and fused with a suitable myeloma cell line. Any suitable myeloma cell line may be employed in accordance with the present invention. After fusion, the resulting hybridoma cells are selectively maintained in HAT medium, and then cloned by limiting dilution as described by (Wands et al. Gastroenterology 80:225-232 (1981)). The hybridoma cells obtained through such a selection are then assayed to identify clones which secrete antibodies capable of binding the chimera.

Antibodies according to the present invention also may be polyclonal, or, preferably, region specific polyclonal antibodies.

Antibodies against the chimera according to the present invention may be used to monitor the amount of chimeric receptor (or chimeric receptor-bearing cells) in a patient. Such antibodies are well suited for use in standard immunodiagnostic assays known in the art, including such immunometric or "sandwich" assays as the forward sandwich, reverse sandwich, and simultaneous sandwich assays. The antibodies may be used in any number of combinations as may be determined by those of skill without undue experimentation to effect immunoassays of acceptable specificity, sensitivity, and accuracy.

Standard reference works setting forth general principles of immunology include Roitt, Essential Immunology, 6th ed., Blackwell Scientific publications, publisher, Oxford (1988); Kimball, Introduction to

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- Immunology, 2nd ed., Macmillan Publishing Co., publisher, New York (1986); Roitt et al., Immunology, Gower Medical Publishing Ltd., publisher, London, (1985); Campbell, "Monoclonal Antibody Technology," in Burdon et al., eds.,
- 5 Laboratory Techniques in Biochemistry and Molecular Biology, volume 13, Elsevier, publisher, Amsterdam (1984); Klein, Immunology: The Science of Self-Nonself Discrimination, John Wiley & Sons, publisher, New York (1982); and Kennett et al., eds., Monoclonal Antibodies,
- 10 Hybridoma: A New Dimension In Biological Analyses, Plenum Press, publisher, New York (1980).

By "detecting" it is intended to include determining the presence or absence of a substance or quantifying the amount of a substance. The term thus

15 refers to the use of the materials, compositions, and methods of the present invention for qualitative and quantitative determinations.

The isolation of other hybridomas secreting monoclonal antibodies of the same specificity as those

20 described herein can be accomplished by the technique of anti-idiotypic screening (Potocmjak et al., Science 215:1637 (1982)). Briefly, an anti-idiotypic antibody is an antibody which recognizes unique determinants present on the antibody produced by the clone of interest. The

25 anti-idiotypic antibody is prepared by immunizing an animal of the same strain used as the source of the monoclonal antibody with the monoclonal antibody of interest. The immunized animal will recognize and respond to the idiotypic determinants of the immunizing

30 antibody by producing antibody to these idiotypic determinants (anti-idiotypic antibody).

For replication, the hybrid cells may be cultivated both in vitro and in vivo. High in vivo production makes this the presently preferred method of

35 culture. Briefly, cells from the individual hybrid

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strains are injected intraperitoneally into pristane-primed BALB/c mice to produce ascites fluid containing high concentrations of the desired monoclonal antibodies. Monoclonal antibodies of isotype IgM or IgG may be  
5 purified from cultured supernatants using column chromatography methods well known to those of skill in the art.

Antibodies according to the present invention are particularly suited for use in immunoassays wherein they  
10 may be utilized in liquid phase or bound to a solid phase carrier. In addition, the antibodies in these immunoassays can be detectably labeled in various ways.

There are many different labels and methods of labeling known in the art. Examples of the types of  
15 labels which can be used in the present invention include, but are not limited to, enzymes, radioisotopes, fluorescent compounds, chemiluminescent compounds, bioluminescent compounds, and metal chelates. Those of ordinary skill in the art will know of other suitable  
20 labels for binding to antibodies, or will be able to ascertain the same by the use of routine experimentation. Furthermore, the binding of these labels to antibodies can be accomplished using standard techniques commonly known to those of ordinary skill in the art.

25 One of the ways in which antibodies according to the present invention can be detectably labeled is by linking the antibody to an enzyme. This enzyme, in turn, when later exposed to its substrate, will react with the substrate in such a manner as to produce a chemical  
30 moiety which can be detected as, for example, by spectrophotometric or fluorometric means. Examples of enzymes which can be used to detectably label antibodies include malate dehydrogenase, staphylococcal nuclease, delta-V-steroid isomerase, yeast alcohol dehydrogenase,  
35 alpha-glycerophosphate dehydrogenase, triose phosphate

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isomerase, biotinavidin peroxidase, horseradish peroxidase, alkaline phosphatase, asparaginase, glucose oxidase,  $\beta$ -galactosidase, ribonuclease, urease, catalase, glucose-VI-phosphate dehydrogenase, glucoamylase, and  
5 acetylcholine esterase.

The presence of detectably labeled antibodies also can be detected by labeling the antibodies with a radioactive isotope which then can be determined by such means as the use of a gamma counter or a scintillation  
10 counter. Isotopes which are particularly useful for the purpose of the present invention are  $^3\text{H}$ ,  $^{125}\text{I}$ ,  $^{32}\text{P}$ ,  $^{35}\text{S}$ ,  $^{14}\text{C}$ ,  $^{51}\text{Cr}$ ,  $^{36}\text{Cl}$ ,  $^{57}\text{Co}$ ,  $^{58}\text{Co}$ ,  $^{59}\text{Fe}$ , and  $^{75}\text{Se}$ .

It is also possible to detect the binding of detectably labeled antibodies by labeling the antibodies  
15 with a fluorescent compound. When a fluorescently labeled antibody is exposed to light of the proper wavelength, its presence then can be detected due to the fluorescence of the dye. Among the most commonly used fluorescent labeling compounds are fluorescein,  
20 isothiocyanate, rhodamine, phycoerythrin, phycocyanin, allophycocyanin, o-phthaldehyde, and fluorescamine.

The antibodies of the invention also can be detectably labeled using fluorescent emitting metals such as  $^{152}\text{Eu}$ , or others of the lanthanide series. These  
25 metals can be attached to the antibody molecule using such metal chelating groups as diethyl-enteriaminepentaacetic acid (DTPA) or ethylenediaminetetraacetic acid (EDTA).

Antibodies also can be detectably labeled by  
30 coupling them to a chemiluminescent compound. The presence of the chemiluminescent-tagged antibody is then determined by detecting the presence of luminescence that arises during the course of the chemical reaction.

Examples of particularly useful chemiluminescent labeling  
35 compounds are luminal, isoluminol, theromatic acridinium

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ester, imidazole, acridinium salts, oxalate ester, and dioxetane.

Likewise, a bioluminescent compound may be used to label the antibodies according to the present invention.

5 Bioluminescence is a type of chemiluminescence found in biological systems in which a catalytic protein increases the efficiency of the chemiluminescent reaction. The presence of a bioluminescent antibody is determined by detecting the presence of luminescence. Important  
10 bioluminescent compounds for purposes of labeling include luciferin and luciferase aequorin.

The antibodies and substantially purified antigen of the present invention are ideally suited for the preparation of a kit. Such a kit may comprise a carrier  
15 means being compartmentalized to receive in close confinement therewith one or more container means such as vials, tubes, and the like, each of said container means comprising the separate elements of the assay to be used.

The types of assays which can be incorporated in  
20 kit form are many and include, for example, competitive and non-competitive assays. Typical examples of assays which can utilize the antibodies of the invention are radioimmunoassays (RIA), enzyme immunoassays (EIA), enzyme-linked immunosorbent assays (ELISA), and  
25 immunometric, or sandwich, immunoassays.

By the term "immunometric assay" or "sandwich immunoassay," it is meant to include simultaneous sandwich, forward sandwich, and reverse sandwich immunoassays. These terms are well understood by those  
30 skilled in the art. Those of skill will also appreciate that antibodies according to the present invention will be useful in other variations and forms of assays which are presently known or which may be developed in the future. These are intended to be included within the  
35 scope of the present invention.

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In the preferred mode for performing the assays it is important that certain "blockers" be present in the incubation medium (usually added with the labeled soluble antibody). The "blockers" are added to assure that non-specific proteins, protease, or human antibodies to mouse immunoglobulins present in the experimental sample do not cross-link or destroy the antibodies on the solid phase support, or the radiolabeled indicator antibody, to yield false positive or false negative results. The selection of "blockers" therefore adds substantially to the specificity of the assays described in the present invention.

It has been found that a number of nonrelevant (i.e., nonspecific) antibodies of the same class or subclass (isotype) as those used in the assays (e.g., IgG<sub>1</sub>, IgG<sub>2a</sub>, IgM, etc.) can be used as "blockers." The concentration of the "blockers" (normally 1-100 µg/µl) is important, in order to maintain the proper sensitivity yet inhibit any unwanted interference by mutually occurring cross-reactive proteins in human serum. In addition, the buffer system containing the "blockers" needs to be optimized. Preferred buffers are those based on weak organic acids, such as imidazole, HEPES, MOPS, TES, ADA, ACES, PIPES, TRIS, and the like, at physiological pH ranges. Somewhat less preferred buffers are inorganic buffers such as phosphate, borate, or carbonate. Finally, known protease inhibitors are preferably added (normally at 0.01-10 µg/ml) to the buffer which contains the "blockers."

There are many solid phase immunoabsorbents which have been employed and which can be used in the present invention. Well known immunoabsorbents include glass, polystyrene, polypropylene, dextran, nylon, and other materials, in the form of tubes, beads, and microtiter plates formed from or coated with such materials, and the

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like. The immobilized antibodies can be either covalently or physically bound to the solid phase immunoabsorbent, by techniques such as covalent bonding via an amide or ester linkage, or by absorption. Those  
5 skilled in the art will know many other suitable solid phase immunoabsorbents and methods for immobilizing antibodies thereon, or will be able to ascertain such, using no more than routine experimentation.

For in vivo, in vitro, or in situ diagnosis,  
10 labels such as radionuclides may be bound to antibodies according to the present invention either directly or by using an intermediary functional group. An intermediary group which is often used to bind radioisotopes which exist as metallic cations to antibodies is  
15 diethylenetriaminepentaacetic acid (DTPA). Typical examples of metallic cations which are bound in this manner are:  $^{99m}\text{Tc}$ ,  $^{123}\text{I}$ ,  $^{111}\text{In}$ ,  $^{131}\text{I}$ ,  $^{97}\text{Ru}$ ,  $^{67}\text{Cu}$ ,  $^{67}\text{Ga}$ , and  $^{68}\text{Ga}$ . The antibodies of the invention can also be labeled with non-radioactive isotopes for purposes of diagnosis.  
20 Elements which are particularly useful in this manner are  $^{157}\text{Gd}$ ,  $^{55}\text{Mn}$ ,  $^{162}\text{Dy}$ ,  $^{52}\text{Cr}$ , and  $^{56}\text{Fe}$ .

The antigen of the invention may be isolated in substantially pure form employing antibodies according to the present invention. Thus, an embodiment of the  
25 present invention provides for substantially pure protein-tyrosine kinase chimera, said antigen characterized in that it is recognized by and binds to antibodies according to the present invention. In another embodiment, the present invention provides a  
30 method of isolating or purifying the chimeric receptor antigen, by forming a complex of said antigen with one or more antibodies directed against the receptor chimera.

The substantially pure chimera antigens of the present invention may in turn be used to detect or  
35 measure antibody to the chimera in a sample, such as

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serum or urine. Thus, one embodiment of the present invention comprises a method of detecting the presence or amount of antibody to protein-tyrosine kinase antigen in a sample, comprising contacting a sample containing an antibody to the chimeric antigen with detectably labeled receptor chimera, and detecting said label. It will be appreciated that immunoreactive fractions and immunoreactive analogues of the chimera also may be used. By the term "immunoreactive fraction" is intended any portion of the chimeric antigen which demonstrates an equivalent immune response to an antibody directed against the receptor chimera. By the term "immunoreactive analogue" is intended a protein which differs from the receptor chimera protein by one or more amino acids, but which demonstrates an equivalent immunoresponse to an antibody of the invention.

By "specifically recognizes and binds" is meant that the antibody recognizes and binds the chimeric receptor polypeptide but does not substantially recognize and bind other unrelated molecules in a sample, e.g., a biological sample.

By "autoimmune-generated cell" is meant cells producing antibodies that react with host tissue or immune effector T cells that are autoreactive; such cells include antibodies against acetylcholine receptors (leading, e.g., to myasthenia gravis) or anti-DNA, anti-erythrocyte, and anti-platelet autoantibodies (leading, e.g., to lupus erythematosus).

By "therapeutic cell" is meant a cell which has been transformed by a chimera of the invention so that it is capable of recognizing and destroying a specific infective agent, a cell infected by a specific agent, a tumor or cancerous cell, or an autoimmune-generated cell; preferably such therapeutic cells are cells of the hematopoietic system.



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By a "target infective agent" is meant any infective agent (e.g., a virus, bacterium, protozoan, or fungus) which can be recognized by a chimeric receptor-bearing therapeutic cell. By a "target cell" is meant  
5 any host cell which can be recognized by a chimeric receptor-bearing therapeutic cell; target cells include, without limitation, host cells which are infected with a virus, bacterium, protozoan, or fungus as well as tumor or cancerous cells and autoimmune-generated cells.

10 By "extracellular" is meant having at least a portion of the molecule exposed at the cell surface. By "intracellular" is meant having at least a portion of the molecule exposed to the therapeutic cell's cytoplasm. By "transmembrane" is meant having at least a portion of the  
15 molecule spanning the plasma membrane. An "extracellular portion", an "intracellular portion", and a "transmembrane portion", as used herein, may include flanking amino acid sequences which extend into adjoining cellular compartments.

20 By "oligomerize" is meant to complex with other proteins to form dimers, trimers, tetramers, or other higher order oligomers. Such oligomers may be homo-oligomers or hetero-oligomers. An "oligomerizing portion" is that region of a molecule which directs  
25 complex (i.e., oligomer) formation.

By "cytolytic" is meant to be capable of destroying a cell (e.g., a cell infected with a pathogen, a tumor or cancerous cell, or an autoimmune-generated) cell or to be capable of destroying an infective agent  
30 (e.g., a virus).

By "immunodeficiency virus" is meant a retrovirus that, in wild-type form, is capable of infecting T4 cells of a primate host and possesses a viral morphogenesis and morphology characteristic of the lentivirus subfamily.  
35 The term includes, without limitation, all variants of

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HIV and SIV, including HIV-1, HIV-2, SIVmac, SIVagm, SIVmnd, SIVsmm, SIVman, SIVmand, and SIVcpz.

By "MHC-independent" is meant that the cellular cytolytic response does not require the presence of an MHC class II antigen on the surface of the targeted cell.

By a "functional cytolytic signal-transducing derivative" is meant a functional derivative (as defined above) which is capable of directing at least 10%, preferably 40%, more preferably 70%, or most preferably at least 90% of the biological activity of the wild type molecule. As used herein, a "functional cytolytic signal-transducing derivative" may act by directly signaling the therapeutic cell to destroy a receptor-bound agent or cell (e.g., in the case of an intracellular chimeric receptor portion) or may act indirectly by promoting oligomerization with cytolytic signal transducing proteins of the therapeutic cell (e.g., in the case of a transmembrane domain). Such derivatives may be tested for efficacy, e.g., using the in vitro assays described herein.

By a "functional HIV envelope-binding derivative" is meant a functional derivative (as defined above) which is capable of binding any HIV envelope protein. Functional derivatives may be identified using, e.g., the in vitro assays described herein.

### Therapeutic Administration

The transformed cells of the present invention may be used for the therapy of a number of diseases. Current methods of administering such transformed cells involve adoptive immunotherapy or cell-transfer therapy. These methods allow the return of the transformed immune-system cells to the bloodstream. Rosenberg, Sci. Am. 62 (May 1990); Rosenberg et al., N. Engl. J. Med. 323:570 (1990).

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The pharmaceutical compositions of the invention may be administered to any animal which may experience the beneficial effects of the compounds of the invention. Foremost among such animals are humans, although the invention is not intended to be so limited.

#### Detailed Description

The drawings will first be described.

#### Description of the Drawings

FIG. 1A is a schematic diagram showing the organization of receptor-kinase fusion proteins of the invention. FIG. 1B shows flow cytometry results for CD16/7/zeta, CD16/7/Lck, CD16/7/Fyn(T), CD16/7/Syk, and CD16/7/ZAP-70 expressed by vaccinia recombinants in Jurkat cells. FIG. 1C shows in vitro kinase activity assays of immunoprecipitated CD16/7/zeta (negative control), CD16/7/Lck, CD16/7/Fyn(T), CD16/7/Syk, and CD16/7/ZAP-70; the lower molecular mass species appearing in the Fyn chimera immunoprecipitate has yet to be identified.

FIG. 2 shows the cytosolic calcium response triggered by crosslinking of kinase chimeras in TCR-negative Jurkat cells. The relative intracellular calcium concentration of the positive population (measured by the ratio of Indo-1 violet to blue fluorescence) is shown. Jurkat cells infected with vaccinia recombinants expressing the different fusion proteins were exposed to anti-CD16 mAb 3G8 followed by phycoerythrin conjugated goat F(ab')<sub>2</sub> antibodies to mouse IgG at time 0. Chimeras based on TCR zeta chain and FcRIIB2 serve as positive and negative controls respectively.

FIG. 3 shows the premature engagement of calcium response in TCR positive cells expressing Syk kinase chimera. Infection and analysis were performed as

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described above for Fig. 2. A substantial proportion of cells expressing Syk chimera showed a high ratio of violet to blue fluorescence prior to addition of primary antibody.

5           FIG. 4A and 4B show an anti-hybridoma killing assay.

FIG. 4A shows the percent  $^{51}\text{Cr}$ -chromate released from hybridoma target cells shown as a function of the ratio of effector cells (CTL expressing kinase chimera) to  
10 target cells; cells expressing receptor chimeras bearing the intracellular domains of TCR zeta chain and FcRIIB2 serve as positive and negative controls respectively. FIG. 4B shows specificity of the killing (absence of bystander killing). BW5147 cells (lacking surface  
15 anti-CD16 antibody) were loaded with  $^{51}\text{Cr}$ -chromate and exposed to CTL expressing kinase chimeras under the same conditions as for a parallel sample of chromate-loaded 3G8 cells (expressing anti-CD16 antibody). No detectable release of chromate was observed from the BW5147 cells.

20           FIG. 5A, 5B, and 5C show that coexpression of ZAP-70 and Fyn or Lck allows induction of cytolysis and reduces latency for the calcium response. CTL were coinfectd with vaccinia recombinants expressing the indicated chimeras and analyzed for cytolytic potential  
25 or calcium mobilization. The efficacy of the chimeras is underestimated by this analysis since the fraction of cells expressing both chimeras was not independently measured (the fraction of cells expressing at least one chimera was used to normalize activity). FIG. 5A shows a  
30 cytolysis assay using CTL expressing pairs of CD16/7/kinase chimeras. FIG. 5B shows calcium response of TCR negative cells expressing pairs of CD16/7/kinase chimeras. FIG. 5C shows a cytolysis assay of CTL coexpressing a CD4/CD7/Fyn chimera and a CD16/CD7/ZAP-70  
35 chimera. CD16/7/zeta chimera serves as the positive

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control, while CD16/7/FcRIIB2 chimera serves as the negative control.

FIG. 6A and 6B show that chimeras bearing kinase deletions or point mutations are ineffective in calcium mobilization and redirected cytolysis. Kinase negative fusion protein variants were constructed by deletion (in the case of Syk) or point mutation (in the case of ZAP-70) and tested for calcium response and cytolysis. FIG 6A shows calcium response in TCR negative cells.

10 FIG. 6B shows a redirected cytolysis assay.

FIG. 7A, 7B, and 7C show that chimeras based on human Syk are essentially equipotent with chimeras based on porcine Syk. FIG. 7A is the sequence of human Syk (SEQ ID NO: 5) and comparison with porcine Syk (SEQ ID NO: 6); the first 11 and last 7 residues are determined by the primer sequences. FIG. 7B shows calcium mobilization analysis of TCR negative cells expressing human Syk chimera. FIG. 7C shows a redirected cytolysis assay of CTL expressing human Syk chimera.

20 FIG. 8 shows changes in tyrosine phosphorylation pattern following crosslinking of chimeric kinases. T cell antigen receptor-negative Jurkat cells expressing the indicated chimeras or pairs of chimeras were treated with anti-CD16 and goat anti-mouse IgG second antibody and then lysed, fractionated on a polyacrylamide gel, transferred to nitrocellulose and probed with anti-phosphotyrosine antibody. Lanes marked '+' represent extracts from cells subjected to crosslinking, while those marked '-' were lysed directly without prior exposure to secondary antibody. Control lanes were created by similar treatment of TCR-negative cells expressing a CD16/7 fusion protein which did not contain an intracellular domain. For comparison, the effects of anti-CD3 treatment of TCR-positive Jurkat cells (with or without wild type vaccinia virus infection) are shown at

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right. The prominent bands in the vicinity of 100kD on the left part of this panel correspond to the expected molecular masses of the kinase chimeras.

FIG. 9 shows tyrosine phosphorylation of phospholipase C- $\gamma$ 1 following aggregation of chimeras. PLC- $\gamma$ 1 was immunoprecipitated from cells subjected to antibody crosslinking and the immunoprecipitates were fractionated on gels, transferred to nitrocellulose, and probed with anti-phosphotyrosine antibody. A substantial increase in phosphorylated PLC- $\gamma$ 1 was seen following aggregation of Syk chimeras, whereas a more limited but easily detectable increase is seen following coaggregation of Fyn and ZAP-70 chimeras.

FIG. 10A and 10B show in vitro kinase assays. Cells expressing chimeric kinases were subjected to antibody-mediated chimera crosslinking, after which the kinases were immunoprecipitated and the immunoprecipitates evaluated for phosphorylation of endogenous substrate. FIG. 10A shows a comparison of the activity of immunoprecipitated kinase chimeras over an incubation period of ten minutes, using immunoprecipitates isolated from crosslinked (+) or uncrosslinked (-) cells. FIG. 10B shows a time course of assimilation of phosphate label into endogenous substrates by Syk kinase chimera, with (+) or without (-) crosslinking.

#### T Cell Activation by Clustered Tyrosine Kinases

There now follows a description of particular embodiments of the invention. In this description, it is demonstrated that nonreceptor kinases are activated by simple clustering events. Artificial receptor kinases were created whose intracellular domains consisted of the complete Src or Syk family kinase sequences and examined for the consequences of aggregation by external

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crosslinking stimuli. A clear distinction emerged between the Syk and Src family kinase activities: crosslinking the latter did not lead to significant cellular activation, while crosslinking the former led to the appearance of free intracellular calcium ion and, in the case of Syk, of cytolytic potential. The failure of ZAP-70 chimeras to induce distal receptor mediated programs could be overcome by coclustering ZAP-70 chimera with either Fyn or Lck kinase chimeras. The examples now described are provided for the purpose of illustrating, not limiting, the invention.

#### Construction of Protein-Tyrosine Kinase Chimeras and Demonstration of Efficacy

Gene fusions encoding proteins resembling cell surface receptor kinases were constructed by appending a DNA fragment encoding the extracellular domain of the CD16 molecule to a short spacer segment encoding the juxtamembranous and transmembrane domains of CD7 joined in turn to the complete coding sequences of the human Lck (Koga et al., Eur. J. Immunol. 16:1643-1646 (1986)), murine Fyn (T) (Cooke and Perlmutter, New. Biol. 1:66-74 (1989)), porcine Syk (Taniguchi et al., J. Biol. Chem. 266:15790-15796 (1991)) and human ZAP-70 (Chan et al., Cell 71:649-662 (1992)) tyrosine kinases (Fig. 1A). The resulting tripartite gene fusions were introduced into recombinant vaccinia viruses by homologous recombination and selection for coexpression of the E. coli gpt gene product. Infection of cells with the recombinants resulted in the efficient cell surface expression of all four kinase chimeras (Fig. 1B). Immunoprecipitation of the resulting protein chimeras with anti-CD16 antibodies revealed the presence of molecular species of the expected masses which were active in an in vitro phosphorylation assay (Fig. 1C).

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We next examined whether crosslinking of the fusion proteins would allow the accumulation of free intracellular calcium in a fashion similar to that found with fusion proteins based on T cell antigen receptor intracellular domains. To do this we infected various cells with vaccinia recombinants and measured the relative cytoplasmic calcium concentration following crosslinking of the extracellular domains with antibodies. Both spectrofluorimetric (bulk population) and flow cytometric (single cell) measurements were performed, with cells loaded with the dye Indo-1 (Grynkiewicz et al., J. Biol. Chem. 260:3440-3450 (1985); Rabinovitch et al., J. Immunol. 137:952-961 (1986)). Flow cytometric analyses were performed on data obtained from cells whose cell surface expression of CD16, as determined by phycoerythrin fluorescence intensity, fell within a relatively narrow predefined range. Although minor variations in mean fluorescence intensity were still observed within this range (due to differences in the underlying distribution of chimeras expressed by the cells), this approach allowed us to contrast the responses of cells bearing approximately the same number of receptors. Figure 2 shows an analysis of data collected from cells of a mutational variant of the Jurkat human T cell leukemia line lacking T cell antigen receptor (Weiss and Stobo, J. Exp. Med. 160:1284-1299 (1984)). In these cells neither Lck nor Fyn chimeras had the capacity to mobilize calcium following crosslinking. In several experiments clustering of the Lck fusion protein resulted in a slight decrease in resting calcium concentration, relative to the negative control, a fusion protein based on the low affinity IgG receptor FcRIIB2 intracellular domain (Kolanus et al., EMBO J. 11:4861-4868 (1992)). Aggregation of fusion proteins based on both ZAP-70 and Syk was highly effective in promoting the



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appearance of free cytoplasmic calcium ion, roughly as effective as aggregation of a similar chimera bearing the intracellular domain of the T cell receptor zeta chain. A slight delay in onset of the calcium response was seen with both ZAP-70 and Syk kinase chimeras, relative to the time of onset of calcium mobilization by zeta chimera. In T cell receptor positive cells (Fig. 3), flux evaluation of Syk chimeras was partially confounded by a high resting concentration of free calcium ion, suggestive of a constitutive engagement of the calcium regulatory apparatus.

Introduction of the chimeras into a cytolytic T cell line then allowed us to assess the fusion proteins' potential to engage effector function. In this assay, anti-CD16 hybridoma cells which express cell surface IgG antibody against CD16 (Fleit et al., Proc. Natl. Acad. Sci. USA 79:3275-3279 (1982); Shen et al., Mol. Immunol. 26:959-969 (1989)) are used as target cells. The hybridoma cells are labeled by incorporation of <sup>51</sup>Cr-chromate and cosedimented with effector cells, prepared by infection of a human allospecific cytotoxic T lymphocyte (CTL) line with vaccinia recombinants expressing the CD16/CD7/kinase fusion proteins. Expression of the chimeric receptor kinases allows the infected CTL cells to bind to the target cells, and if competent, to lyse them, a process which is measured by release of the incorporated <sup>51</sup>Cr-chromate. The relative potency of the armed CTL is determined by comparison of the ratio of effector to target cells needed to achieve a given proportion of <sup>51</sup>Cr release. Fig. 4A shows that CTL expressing chimeric receptors comprising the Src family kinases Lck or Fyn (T), or the Syk family kinase ZAP-70, are incapable of mediating cytolysis against anti-CD16 hybridoma targets. However CTL expressing a kinase chimera based on the Syk protein product were essentially

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as effective as CTL expressing a chimera composed of CD16 fused in the same manner to the intracellular domain of the T cell receptor zeta chain. The cytolytic activity directed by the CD16/CD7/kinase chimeras could not be ascribed to a nonspecific release of cytotoxic granules because cosedimentation of an irrelevant chromium-laden target with the kinase-armed CTL did not result in detectable release of labeled chromium (Fig. 4B).

The disparity between Syk and ZAP-70 activities in the cytolysis assay was unexpected in light of the similar activities of the two chimeras in the calcium response assay. In light of the demonstration that coexpression of nonchimeric ZAP-70 and Src-family kinases led to activation in COS cells (Chan et al., Cell 71:649-662 (1992)), we undertook an evaluation of the relative potential of pairs of kinase chimeras to effect cytolysis. CTL effectors were coinfecting with recombinant vaccinia viruses encoding ZAP-70 and Lck chimeras, ZAP-70 and Fyn (T) chimeras, or Lck and Fyn (T) chimeras. Fig. 5A shows that the coexpression of ZAP-70 and Fyn (T) chimeras, or ZAP-70 and Lck chimeras, endowed CTL with an activity essentially equipotent with that of CTL expressing CD16/CD7/Syk kinase chimeras alone, an activity in turn as potent as that displayed by CD16/CD7/zeta chimeras. Coexpression of Lck and Fyn(T) chimeras did not allow significant cytolytic potential to be redirected against anti-CD16 target cells (Fig. 5A). Evaluation of the calcium mobilization potential of cells coinfecting with pairs of kinase fusion proteins showed that coexpression of ZAP-70 and Src family kinase chimeras increased the rapidity with which calcium was mobilized in response to receptor crosslinking and that coexpression of Lck and Fyn(T) chimeras did not result in a significant accumulation of free intracellular calcium (Fig. 5B). To further explore the role of the Fyn

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chimera in the activation response induced by coaggregation, we prepared a Fyn chimera consisting of the extracellular and transmembrane domains of CD4 fused to Fyn in a manner similar to that of the CD16 chimeras.

5 Fig. 5C shows that the effectiveness of this chimera in there directed cytolysis assay is ten to twenty fold lower than that of the comparable CD16 chimera, suggesting that physical association of the chimeric kinases is important for activation. However the  
10 cytolytic activity of cells expressing the two chimeras is significantly greater than would be observed for cells expressing ZAP-70 chimera alone. Because of the relatively high level of kinase expression in this system, it cannot be excluded that the residual activity  
15 reflects spontaneous random association of the CD4/Fyn chimera with CD16/ZAP-70.

To establish that the activation seen in both calcium response and cytolysis assays was directly attributable to the relevant kinase activity and not to  
20 passive association of the kinases with existing signal transduction elements whose indirect aggregation then initiated the activation response, we created kinase negative variants of both the porcine Syk and human ZAP-70 receptor chimeras. Fig. 6 shows that receptor  
25 chimeras lacking either substantially all of the kinase domain (in the case of Syk) or bearing a point mutation abrogating phosphotransferase activity (in the case of ZAP-70) lacked in vitro kinase activity and were incapable of mediating calcium mobilization following  
30 crosslinking, or of mediating receptor redirected cytolysis.

Because the interaction of porcine Syk with the human cellular apparatus might not be identical to the interaction of human Syk, we also constructed similar  
35 protein chimeras based on human Syk, after isolating

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human Syk sequences by PCR with primers corresponding to the amino and carboxyl termini of the porcine protein sequence. Fig. 7A shows that pig and human Syk are strikingly similar proteins, as suggested by analysis of PCR products corresponding to portions of the kinase and second SH2 domains (Chan et al., Cell 71:649-662 (1992)). Consonant with this, human Syk chimeric receptor proteins behaved essentially identically to the porcine constructs in calcium release and cytolysis assays (Fig. 7B and 7C).

To establish whether aggregation of the chimeric tyrosine kinases results in a significant change in the abundance of phosphotyrosine proteins, T cell receptor negative cells were infected with vaccinia recombinants encoding the chimeric kinases. The extracellular domains of the chimeras were crosslinked with antibodies, and total cellular lysates of the activated cells were fractionated by electrophoresis, transferred to membranes and analyzed with an antibody recognizing phosphotyrosine. Lysates were prepared by disruption of cells in nonionic detergents in the presence of vanadate with or without EDTA, or by lysis in the presence of sodium dodecyl sulfate, followed by sonication to shear the liberated DNA. The pattern of phosphotyrosine proteins was different in each case and lysates prepared with vanadate but without EDTA showed additional species not present in lysates prepared in SDS alone, suggesting that EDTA may inhibit the postlysis action of tyrosine kinases as well as phosphatases. The use of direct lysis in SDS was found to lead to more reproducible patterns of protein tyrosine phosphorylation than lysis with nonionic detergents in the presence of EDTA and vanadate. Fig. 8 shows that aggregation of chimeras bearing Syk, ZAP-70, or Fyn plus ZAP-70 results in the appearance or increased phosphorylation of several protein species comigrating with proteins which show increased phosphorylation

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following antigen receptor crosslinking. In particular, the pattern of bands induced by Syk chimera clustering is very similar to the pattern induced by anti-CD3 antibody in T cell receptor-positive cells (Fig. 8). Among these  
5 is an approximately 150 kD protein induced by aggregation of Syk chimera, but also induced by coaggregation of Fyn and ZAP-70 chimeras. In preliminary experiments this phosphoprotein was observed to comigrate with phospholipase C- $\gamma$  (data not shown).

10 To establish the effects of kinase chimera clustering on PLC- $\gamma$  directly, we crosslinked chimeras, precipitated PLC- $\gamma$  with a mixture of monoclonal antibodies, and analyzed the resulting immunoprecipitates for the presence of phosphotyrosyl proteins. Fig. 9  
15 shows that clustering of Syk results in a substantial increase in the tyrosine phosphate content of PLC- $\gamma$ , while cocrosslinking of Fyn plus ZAP-70 chimeras results in a less dramatic but easily detectable increase in tyrosine phosphate. Cells expressing Fyn chimera alone  
20 showed a modest basal phosphorylation of PLC- $\gamma$  which did not increase following receptor aggregation (Fig. 9). Whether the same tyrosine residues are phosphorylated by Syk, Fyn, or ZAP-70 plus Fyn, is presently unknown. Because cells expressing Fyn chimera showed neither  
25 resting nor induced calcium mobilization, the phosphotyrosine signal seen in these cells may represent utilization of other sites on PLC- $\gamma$  than those which mediate phospholipase activation.

In a preliminary attempt to account for the  
30 changes in phosphotyrosine pattern we evaluated the activity of the various kinases following clustering in an in vitro autophosphorylation assay. Chimeras were aggregated, immunoprecipitated, and evaluated for their ability to incorporate phosphate label into the protein  
35 species present in the immunoprecipitate. Fig. 10A shows

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that under these conditions no increase in kinase activity was detected following crosslinking when the kinase assay was carried out for ten minutes. Although incorporation of labeled phosphate continues to increase for up to 30 minutes in this assay, it is unclear what factors limit activity; in particular the observed kinetics may be dominated by the rate of dissociation of the immune complexes, allowing kinase diffusion to unutilized substrate. In an attempt to control for this effect, as well as to maximize the sensitivity of the assay, we also evaluated Syk kinase activity with or without prior crosslinking over a very brief time course from 5 to 30 seconds; however here too there was no significant increase in kinase activity (Fig. 10B). Although at present we cannot exclude the possibility that an increase in activity would be demonstrable with an appropriate substrate, an aggregation-induced increase in Syk chimera activity was also not observed when an exogenous peptide substrate (a Y 19 K substitution of cdc 2 residues 6-20) was used to measure kinase activity.

#### Possible Mechanisms

The mechanism by which a simple physical stimulus, receptor aggregation, results in the transmission of a distinctive chemical signal to immune system cells remains unknown. Previous studies have established that Src-family kinases can be found associated with many of the important aggregation-activated receptors of the immune system, and that crosslinking of such receptors frequently leads to increased kinase activity. More recently, the related Syk and ZAP-70 kinases have been found to associate either stably (in the case of Syk) or transiently (in the case of ZAP-70) with the B and T cell antigen receptors, respectively, and at least in the case

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of Syk, receptor crosslinking has been reported to result in increased kinase activity.

In this work we have shown that aggregation of Syk family kinases, but not the Src family kinases Lck or Fyn, leads to a calcium response in cells lacking T cell receptor. The response appears not to be due to an indirect association with other T cell receptor or signal transduction components because kinase negative mutants can not induce the calcium response. Aggregation of chimeras containing the Syk kinase is sufficient to allow induction of specific cytolysis, while induction of similar cytolysis by ZAP-70 chimera requires the additional participation of a Src family kinase. At present it is unclear which of the Syk family kinases is likely to play a more important role in T cell activation: both ZAP-70 and Syk are expressed in T cells, including the cell lines used in this study, and at least one responsive human T cell line contains Syk but not ZAP-70 as judged by specific PCR amplification products. The pattern of increased protein tyrosine phosphorylation seen following Syk chimera clustering is very similar to the pattern seen after crosslinking of the T cell antigen receptor.

One simple model for activation of immune system cells by nonreceptor tyrosine kinases invokes a receptor-associated kinase whose aggregation leads to activation either by physical association (e.g., by forming active kinase dimers) or by mutual enzymatic action (e.g., crossphosphorylation); the activated enzyme then acts on key intracellular substrates required for calcium mobilization and inositolphosphate synthesis. Support for this sequence of events can be found in studies reporting increases in receptor-associated kinase activity following receptor crosslinking (e.g., Bolen et al., Adv. Cancer Res. 57:103-149 (1991); Burkhardt et

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al., Proc. Natl. Acad. Sci. USA 88:7410-7414 (1991);  
Eiseman and Bolen, Nature 355:78-80 (1992); Hutchcroft et  
al., Proc. Natl. Acad. Sci. USA 89:9107-9111 (1992);  
Hutchcroft et al., J. Biol. Chem. 267:8613-8619 (1992);  
5 Tsygankov et al., J. Biol. Chem. 267:18259-18262 (1992);  
Wong et al., Oncogene 7:2407-2415 (1992)). However the  
reported changes in kinase activity are in most cases  
modest, and contrast with the dramatic changes in  
phosphotyrosyl protein pattern seen in vivo. Because it  
10 is difficult to unambiguously rule out activation by weak  
allosteric interactions using in vitro kinase assays as a  
tool, we cannot at this point make a definitive statement  
about the relative importance of kinase activation in the  
initiation of signal transduction. But the data  
15 presented here suggest that aggregation-induced  
repartitioning of enzyme and substrate may be an  
important factor in directing an existing activity toward  
the appropriate physiological target.

Aggregation of chimeras based on Syk family  
20 kinases led to a calcium response which was slightly  
delayed but similar in amplitude to the response seen  
following aggregation of zeta receptor chimeras in cells  
lacking endogenous T cell receptor. A more profound  
delay in the appearance of free calcium ion was observed  
25 following ZAP-70 chimera crosslinking, and this delay  
could be substantially abolished by cocrosslinking ZAP-70  
and Fyn chimeras. At present the explanation for the  
observed latency is unclear. Because cocrosslinking  
accelerated calcium mobilization, it is tempting to  
30 ascribe the delay to the relative inefficacy of ZAP-70  
for aggregation-mediated autoactivation. But other  
factors may be equally important, and the tethering of  
ZAP and Syk kinases at the cell surface may actually be  
an impediment to activation when compared to the normal  
35 process; for example if in the normal course of events



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Syk family kinases are transiently recruited to clustered receptors, activated and then released to diffuse to their substrates, the permanent linkage of the kinase domain to the plasma membrane could be restrictive by  
5 hindering access to substrate and/or limiting signal amplification due to the inability of the chimeric receptors to function as a kind of catalytic center for kinase activation.

A second peculiarity of the calcium response was  
10 the finding that T cell receptor positive cells expressing chimeras based on human or porcine Syk showed a high baseline concentration of free calcium ion, suggesting that calcium release had been spontaneously triggered. A similar finding was not observed in  
15 receptor negative cells. This result runs counter to a general trend we have observed, in which T cell receptor negative mutants of human T cell tumor lines typically are hyperresponsive to exogenously introduced trigger molecules. To account for the apparent requirement for T  
20 cell receptor in the spontaneous activation process, we propose two possible and related explanations. One is that chimeric Syk kinase may act constitutively on T cell receptor intracellular domains to create phosphotyrosine targets for the SH2 domains of the receptor chimera,  
25 leading to intracellular aggregation through a multivalent T cell receptor bridge, in turn promoting kinase activation. Another possibility is that the T cell receptor negative cell line may have lower levels of a membrane associated kinase required for activation of  
30 Syk, either because a global regulatory circuit results in decreased de novo synthesis of the hypothetical kinase, or because the absence of antigen receptor results in a disregulated intracellular trafficking.

In B cells, the Syk kinase has been reported to be  
35 constitutively associated with the intracellular elements

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of the IgM antigen receptor (Hutchcroft et al., Proc. Natl. Acad. Sci. USA 89:9107-9111 (1992); Hutchcroft et al., J. Biol. Chem. 267:8613-8619 (1992)). The exact mechanism of this association is unclear, but one possibility is that phosphotyrosine is not required for interaction of Syk SH2 domains with the tyrosine trigger motif present in the cytoplasmic domain of the mb-1 and B29 receptor chains. A partial precedent for this suggestion is the report that the Philadelphia chromosome breakpoint cluster region gene product BCR binds to a variety of SH2 domains in a phosphotyrosine independent manner (Pendergast et al., Cell 66:161-171 (1991); Muller et al., Mol. Cell. Biol. 12:5087-5093 (1992)). In this case, though, it appears likely that phosphoserine and/or phosphothreonine residues play a critical role in the interaction. Alternatively, Syk may associate with IgM receptor intracellular motifs through the unique region located between the Syk SH2 elements and the catalytic domain. A third possibility is that only a very small amount of tyrosine phosphorylated peptide is necessary to recruit functionally important levels of Syk to the inner face of the plasma membrane, and this low level of tyrosine phosphate has thus far escaped detection.

Although in B cells the requirement for a Src family kinase in activation has not been definitively established, in T cells two kinases, Lck and Fyn (T) have been shown by somatic or organismic genetics to play important roles (Appleby et al., Cell 70:751-763 (1992); Karnitz et al., Mol. Cell. Biol. 12:4521-4530 (1992); Stein et al., Cell 70:741-750 (1992); Straus and Weiss, Cell 70:585-593 (1992)). At present we cannot conclusively establish whether the action of these kinases normally precedes or follows the action of the Syk family kinases. One hypothesis accounting for the action of ZAP-70 in T cell activation invokes a

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receptor-associated Src family kinase whose aggregation permits a transitory phosphorylation of receptor chains in turn leading to association of ZAP-70 and subsequent cellular activation. The initial phosphorylation of  
5 receptor chains proposed in this model must be distinguished from the stable phosphorylation of zeta seen at longer times following receptor crosslinking.

In murine T cells a small proportion of T cell receptor complexes contain a zeta-related molecule called  
10 eta (Baniyash et al., J. Biol. Chem. 263:9874-9878 (1988)) which represents an alternatively spliced form (Clayton et al., Proc. Natl. Acad. Sci. USA 88:5202-5206 (1991)). Eta differs from zeta at the carboxyl terminus, and lacks the most distal of the six tyrosines found in  
15 murine zeta (Jin et al., Proc. Natl. Acad. Sci. USA 87:3319-3323 (1990)). Although the phosphorylation of the zeta chain of murine TCR zeta-zeta isoforms can readily be detected following antibody-mediated receptor crosslinking, under similar circumstances the TCR eta  
20 chain is not detectably phosphorylated (Bauer et al., Proc. Natl. Acad. Sci. USA 88:3842-3846 (1991)). Stable phosphorylation of the zeta chain appears to require two closely apposed zeta chains since TCR isoforms bearing zeta-eta heterodimers are not phosphorylated following  
25 receptor crosslinking (Bauer et al., Proc. Natl. Acad. Sci. USA 88:3842-3846 (1991)). Despite the differences in phosphorylation, cell lines comprising TCR isoforms consisting solely of eta homodimers are functionally indistinguishable from cell lines bearing only zeta  
30 homodimers (Bauer et al., Proc. Natl. Acad. Sci. USA 88:3842-3846 (1991)). Thus phosphorylation of zeta, as observed 30 minutes after antibody mediated receptor aggregation, does not correlate with activation. In a separate study, examination of the time course of  
35 accumulation of phosphotyrosine phosphoproteins following

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TCR aggregation has shown that the earliest observable species are two proteins of mass 135 and 100 kD, whose phosphorylation is first detectable at five and fifteen seconds after crosslinking, respectively, and whose half maximal phosphorylation, in both cases at approximately 30 seconds, precedes the times of half maximal calcium mobilization and inositol phosphate formation (June et al., Proc. Natl. Acad. Sci. USA 87:7722-7726 (1990); June et al., J. Immunol. 144:1591-1599 (1990)). By contrast, the rate of phosphorylation of zeta is substantially slower, leading to half maximal substitution at approximately three to five minutes post-stimulation, well after calcium accumulation and liberation of inositol phosphates are observed (June et al., Proc. Natl. Acad. Sci. USA 87:7722-7726 (1990); June et al., J. Immunol. 144:1591-1599 (1990)).

Thus if the two step model is correct, the tyrosine phosphorylation necessary to recruit ZAP-70 to the inner face of the plasma membrane must be a more rapid, presumably transitory, event than observed in the studies above. Recently it has been suggested that tyrosine phosphorylation with an appropriately fast (ca. fifteen second) onset can be detected on both zeta and CD3 epsilon chains following receptor crosslinking (Wange et al., J. Biol. Chem. 267:11685-11688 (1992)), and that a 70 kD protein bearing tyrosine phosphate can be found associated with both zeta and epsilon chains. It is not presently clear whether a stable association with phosphorylated receptor chains is a prerequisite for successful T cell activation.

As a general assertion, though, the results reported here suggest that Syk family kinases act more directly on the effector apparatus of T cells than Src family kinases. An increasing body of evidence suggests that Src family kinases can associate with a number of

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cell surface molecules which are not members of the antigen/Fc receptor family, including CD2 (Bell et al., Mol. Cell. Biol. 12:5548-5554 (1992)), CD23 (Sugie et al., Proc. Natl. Acad. Sci. USA 88:9132-9135 (1991)),  
5 CD36 (Huang et al., J. Biol. Chem. 267:5467-5473 (1992)), IL-2 receptor beta chain (Hatakeyama et al., Science 252:1523-1528 (1991)) and various phosphatidylinositol anchored proteins (Stefanova et al., Science 254:1016-1019 (1991); Thomas and Samelson, J. Biol. Chem.  
10 267:12317-12322 (1992)), some of which are known to require the additional presence of the antigen receptor to promote activation in T cells. A simple explanation for the latter requirement may be that the trigger motifs on the antigen receptor act as substrates for Src family  
15 kinases, allowing the subsequent docking of Syk family kinases, followed perhaps by some modifying event promoting their activation. Given the difficulty of establishing a causal chain of phosphorylation and activation it may also be that the trigger motifs have  
20 only a transitory role, to act as a kind of catalytic center for the recruitment, activation, and release of effector kinases.

Src family kinases are broadly distributed throughout nonhematopoietic lineages, and recent studies  
25 using Fyn negative mice have shown a role for Fyn in the sustenance of long term potentiation, the phenomenon of facilitated synaptic transmission thought to underlie the initial consolidation of associative memory (Grant et al., Science 258:1903-1910 (1992)). If similar  
30 activation pathways are mediated by Src family kinases in other cell types, Syk family kinases may also prove to be more extensively distributed throughout the extrahematopoietic compartments.

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### Experimental Methods

Construction of chimeras. The entire coding regions of the human Lck (Koga et al., Eur. J. Immunol. 16:1643-1646 (1986)), murine Fyn (T) (Cooke and Perlmutter, New. Biol. 1:66-74 (1989)), porcine Syk (Taniguchi et al., J. Biol. Chem. 266:15790-15796 (1991)) and human ZAP-70 (Chan et al., Cell 71:649-662 (1992)) kinases were attached to the intracellular domain of a chimeric transmembrane protein consisting of the CD16 extracellular domain joined to a short 'stalk' segment and transmembrane domain of CD7. The CD7 intracellular domain was truncated at the stop transfer sequence by addition of an Mlu site. The various kinases were adapted with an Mlu site in the appropriate reading frame to allow a tripartite fusion protein to be expressed. The pig Syk sequence was obtained by reverse transcription and PCR of total pig lymphocyte RNA using primers bearing appropriate restriction sites. ZAP-70 sequences were similarly obtained by PCR from a human T cell cDNA library. Several isolates were sequenced in parallel and a mutation-free coding sequence was derived for each kinase by restriction fragment interchange. The resulting coding sequences were inserted into a vaccinia virus expression vector downstream from the CD16/CD7 sequences. Human Syk was isolated from a natural killer cell cDNA library and from a Daudi cell library using primers corresponding to the ends of the porcine sequence. The forward primer bore the sequence atg gca gac agt gcc aac cac ttg ccc ttc ttc t (SEQ ID NO: 7) and the reverse primer bore the sequence cgc ggg gcg gcc gct tta att cac cac gtc gta gta gta (SEQ ID NO: 8). After initial amplification revealed the presence of bands of the expected size a reamplification (10 cycles) was performed using an extension primer at the 5' end having the sequence cgc ggg acg cgt acc atg gca gac agt gcc aac (SEQ

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ID NO: 9), allowing the fragment to be ligated to an Mlu I-cut vector.

Calcium mobilization analysis. Flow cytometric and bulk spectrophotometric analyses were conducted on cells

5 expressing recombinant kinases using the calcium sensitive fluorophore Indo-1 as previously described (Romeo and Seed, Cell 64:1037-1046 ((1991); Romeo et al., Cell 68:889-897 (1992)). Briefly, cells of the Jurkat mutant subline JRT 3.T 3.5 (Weiss and Stobo, J. Exp. Med. 10 160:1284-1299 (1984)) were infected with recombinant vaccinia viruses for one hour in serum free IMDM at an moi of 10 and incubated for three to nine hours in IMDM, 10% FBS. Cells were collected by centrifugation and resuspended at  $3 \times 10^6$ /ml in complete medium containing

15 1mM Indo-1 acetomethoxyester (Grynkiewicz et al., J. Biol. Chem. 260:3440-3450 (1985)) (Molecular Probes, Eugene, OR) and incubated at 37°C for 45 minutes. The Indo-1 loaded cells were pelleted and resuspended at  $1 \times 10^6$ /ml in serum free IMDM and stored at room temperature

20 in the dark. Cells were analyzed for free calcium ion by simultaneous measurement of the violet and blue fluorescence emission by flow cytometry (Rabinovitch et al., J. Immunol. 137:952-961 (1986)). To initiate calcium flux, either unconjugated 3G8 (anti-CD16)

25 monoclonal antibody (at 1  $\mu$ g/ml) was added to the cell suspension followed by 10  $\mu$ g/ml of phycoerythrin (PE)-conjugated F(ab')<sub>2</sub> goat anti-mouse IgG at time 0, or a PE-conjugated anti-CD4 antibody (Leu-3a, Becton Dickinson) was added, followed by unconjugated second

30 antibody. Histograms of the violet/blue emission ratio were collected from the PE positive (infected) cell population, which typically represented 40-80% of the cells. The violet/blue emission ratio prior to the

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addition of antibody was used to establish the normalized initial ratio, set equal to unity.

Lymphocyte cytotoxicity assay. A CD8<sup>+</sup> CD4<sup>-</sup> HLA B44 restricted cytolytic line (WH3) was maintained in IMDM, 10% human serum with 100 U/ml of IL-2 and was periodically stimulated with irradiated (3000 rad) mononuclear cells having the HLA B44 haplotype. Cells were grown for at least 10 days following stimulation before use in cytotoxicity assays. The cells were infected with recombinant vaccinia at a multiplicity of infection of at least 10 for one hour in serum free medium, followed by incubation in complete medium for three hours. Cells were harvested by centrifugation and resuspended at a density of  $1 \times 10^7$ /ml. 100  $\mu$ l were added to each well of a U-bottom microtiter plate containing 100  $\mu$ l/well of complete medium. Cells were diluted in two-fold serial steps. Two wells for each sample did not contain lymphocytes, to allow spontaneous chromium release and total chromium uptake to be measured. An aliquot of  $10^6$  3G8 10-2 target cells (Shen et al., Mol. Immunol. 26:959-969 (1989)) or was centrifuged and resuspended in 50  $\mu$ l of sterile <sup>51</sup>Cr sodium chromate (1 m Ci/ml, DuPont) for one hour at 37°C with intermittent mixing, then washed three times with PBS. 100  $\mu$ l of labelled cells resuspended in medium at  $10^5$ /ml were added to each well. The microtiter plate was spun at 750 x g for 1 minute and incubated for 4 hours at 37°C. At the end of the incubation period the cells in each well were resuspended by gentle pipetting, a sample removed to determine the total counts incorporated, and the microtiter plate was spun at 750 x g for 1 minute. 100  $\mu$ l aliquots of supernatant were removed and counted in a gamma ray scintillation counter. The effector to



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target ratio was corrected for the percent of effector cells infected (usually >70%).

Creation of mutant kinase chimeras. A porcine Syk kinase negative fusion protein variant was created by cleavage  
5 of the chimera with Stu I and Not I (the latter lying just 3' to the carboxyl terminus), filling in the Not I site, and ligating the ends together. The resulting sequence joined the first 298 residues of pig Syk to 4  
extraneous residues (GPRL) before terminating. A point  
10 mutation (K369G) in the ATP binding site of ZAP-70 was created by insertion of a duplex oligonucleotide fragment between the BallI and EarI sites located between  
nucleotide residues 1319 and 1345 of the top strand of the sequence reported by (Chan et al. Cell 71:649-662  
15 (1992)). The resulting sequence encoded glycine at residue 369 in place of lysine.

Immunoprecipitation and kinase assay. Approximately  $2 \times 10^6$  HeLa S3 cells were infected for one hour in serum free DME medium with recombinant vaccinia at a  
20 multiplicity of infection of at least ten. Five hours after infection, the cells were harvested, washed twice with phosphate buffered saline, and lysed in 1% Triton X-100, 0.15 M NaCl, 0.02 M HEPES pH 7.3, 5 mM EDTA, 5 mM NaF, 0.2 mM  $\text{Na}_3\text{VO}_4$ , 10  $\mu\text{g/ml}$  leupeptin, 10  $\mu\text{g/ml}$   
25 aprotinin, and 1mM PMSF. After a 10 min. incubation on ice, the nuclei were removed by centrifugation and the CD16 fusion proteins immunoprecipitated with antibody BMA209/2 and protein-A sepharose. The fusion protein loaded resin was washed 3 times with lysis buffer  
30 followed by a final wash with 20 mM Hepes pH 7.3. To each sample was added 10  $\mu\text{l}$  of kinase buffer (20 mM Hepes pH 7.3, 10 mM  $\text{MgCl}_2$ , 10 mM  $\text{MnCl}_2$ ) containing 10  $\mu\text{Ci}$  of [ $\gamma$ - $^{32}\text{P}$ ]ATP (>3000 Ci/mmole). The reactions were allowed to

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incubate at room temperature for 10 min. and terminated by the addition of 20  $\mu$ l of 2X sample loading buffer (4% SDS, 100 mM Tris pH6.8, 20% glycerol, and 10%  $\beta$ -mercaptoethanol). After the samples were boiled for 3 min., aliquots were run on a 4-15% gradient gel. Kinase assays with a soluble peptide substrate corresponding to positions 6-20 of cdc 2, in which tyr 20 was replaced with lys, were performed according to the manufacturer's recommendations (UBI).

- 10 Immunoblot analysis of protein tyrosine phosphorylation.  
TCR negative 3.5 cells were infected with recombinant virus stocks (moi of at least 10) for one hour. Cells were subsequently incubated at 37°C for 8-12 hours, centrifuged, washed and resuspended in Iscove's medium  
15 without serum at  $10^7$  cells per ml. Aliquots of cells were incubated with anti-CD16 mAb (3G8, Medarex or BMA209/2, Behringwerke) at 1  $\mu$ g antibody per  $2 - 3 \times 10^6$  cells. Stimulated samples were further incubated with a 3-5 fold excess of an affinity purified anti-mouse IgG1  
20 antibody (Southern Biotechnology) for 5 min. Cells were subsequently processed according to Secrist et al., J. Biol. Chem. 268:5886-5893 (1993) with slight modifications. Incubations were terminated by adding SDS to a final concentration of 1%, and samples were boiled  
25 for three minutes. DNA was sheared by sonication for 1 min using a Heat Systems Ultrasonics, Inc., 2X sample buffer was added, and aliquots corresponding to  $10^5$  to  $2.5 \times 10^5$  cells were separated on polyacrylamide gels and the proteins transferred by semidry electroblotting  
30 (Hoefer) onto nitrocellulose (Schleicher and Schuell BA45). Filters were blocked for one hour in Tris Buffered Saline with 0.05% Tween-20 (TBST) containing 1.5% chicken ovalbumin (Sigma), washed in TBST, and transferred into solution containing anti-phosphotyrosine

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antibody 4G10 (UBI) at a 1:10000 dilution and incubated at 22° for 1-2h. After TBST washes, filters were incubated in TBST and a 1:5000 dilution of anti-mouse horseradish peroxidase conjugate for 1 hour

- 5 Phosphorylated protein bands were detected by chemiluminescence (ECL, Amersham). Exposure times varied between 2 seconds and 5 minutes.

#### Construction of Human IgG1:Protein-Tyrosine Kinase Chimeras

- 10 Chimeric molecules may be produced which include the extracellular domain of an antibody molecule specific for a target cell and the intracellular domain of a protein-tyrosine kinase (e.g., those kinases described herein). To produce such a molecule, human IgG1 heavy  
15 chain sequences are prepared by joining sequences in the C<sub>H</sub>3 domain to a cDNA fragment derived from the 3' end of the transmembrane form of the antibody mRNA. The 3' end fragment is obtained by polymerase chain reaction using a tonsil cDNA library as substrate, and oligonucleotides  
20 having the sequences:

CGC GGG GTG ACC GTG CCC TCC AGC AGC TTG GGC (SEQ ID NO: 1) and

CGC GGG GAT CCG TCG TCC AGA GCC CGT CCA GCT CCC CGT CCT GGG CCT CA (SEQ ID NO: 2),

- 25 corresponding to the 5' and 3' ends of the desired DNA fragments respectively. The 5' oligo is complementary to a site in the C<sub>H</sub>1 domain of human IgG1, and the 3' oligo is complementary to a site just 5' of the sequences encoding the membrane spanning domain. The PCR product  
30 is digested with BstXI and BamHI and ligated between BstXI and BamHI sites of a semisynthetic IgG1 antibody gene bearing variable and constant regions. Following the insertion of the BstXI to BamHI fragment, the amplified portions of the construct are replaced up to

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the SmaI site in C<sub>H</sub>3 by restriction fragment interchange, so that only the portion between the SmaI site and the 3' oligo is derived from the PCR reaction.

To create a human IgG1 chimeric receptor, the heavy chain gene ending in a BamHI site is joined to the kinase intracellular domain of interest by standard techniques. Levels of chimeric receptor expression may be determined by flow cytometry. Increases in expression may be accomplished by coexpression of a plasmid encoding an antibody light chain cDNA.

To create a single transcription unit which would allow both heavy and light chains to be expressed from a single promoter, a plasmid encoding a bicistronic mRNA is created from heavy and light chain coding sequences, and the 5' untranslated portion of the mRNA encoding the 78kD glucose regulated protein, otherwise known as grp78, or BiP. grp78 sequences are obtained by PCR of human genomic DNA using primers having the sequences:

CGC GGG CGG CCG CGA CGC CGG CCA AGA CAG CAC (SEQ ID NO: 3) and

CGC GTT GAC GAG CAG CCA GTT GGG CAG CAG CAG (SEQ ID NO: 4)

at the 5' and 3' ends respectively. Polymerase chain reactions with these oligos are performed in the presence of 10% dimethyl sulfoxide. The fragment obtained by PCR is digested with NotI and HincII and inserted between NotI and HpaI sites downstream from human IgG1 coding sequences. Sequences encoding a human IgG kappa light chain cDNA are then inserted downstream from the grp78 leader, using the HincII site and another site in the vector. The expression plasmid resulting from these manipulations consists of the semisynthetic heavy chain gene, followed by the grp78 leader sequences, followed by the kappa light chain cDNA sequences, followed by polyadenylation signals derived from an SV40 DNA

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fragment. We have previously demonstrated that transfection of COS cells with this expression plasmid gave markedly improved expression of heavy chain determinants, compared to transfection of plasmid encoding heavy chain determinants alone.

To create a bicistronic gene comprising a heavy chain/receptor chimera and a light chain, the upstream heavy chain sequences can be replaced by any chimeric heavy chain/ receptor gene described herein.

Once constructed, the IgG-tyrosine kinase chimeras may be cloned into an expression vector, introduced into a host cell, and tested by any of the assays described herein (e.g., by calcium mobilization or cytolysis assays).

#### 15 Construction of CD4-Tyrosine Kinase Chimeras

Chimeric molecules may be produced which include the extracellular domain of the CD4 molecule and the intracellular domain of a protein-tyrosine kinase (e.g., those kinases described herein). To produce such a molecule, the tyrosine kinase-encoding sequence (for example, cDNA) is isolated (for example, as described above). This sequence is then joined to the extracellular domain of an engineered form of CD4 possessing a BamHI site just upstream of the membrane spanning domain (Aruffo et al., Proc. Natl. Acad. Sci. USA 84:8573-8577 (1987); Zettlmeissl et al., DNA Cell Biol. 9:347-353 (1990)) by standard techniques. To form this fusion protein, a BamHI site may be engineered into the sequence at the appropriate location (again, by standard techniques). The gene fusions are introduced into a vaccinia virus expression plasmid (as described herein), and inserted into the genome of the vaccinia WR strain by homologous recombination and selection for growth in mycophenolic acid (Falkner et al., J. Virol.

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62:1849-1854 (1988); Boyle et al., Gene 65:123-128 (1988)). Flow cytometric analysis is used to examine expression by the vaccinia recombinants of the CD4-tyrosine kinase fusion proteins at the cell surface.

- 5 Immunoprecipitation of cells infected with the vaccinia recombinants is used to confirm the results (as described above).

The efficacy of CD4 chimeras may be tested by any of the calcium mobilization or cytolysis assays described  
10 herein. In one particular example, a model target:effector system based on CD4 recognition of the HIV envelope gp120/gp41 complex is created. HeLa cells are infected with recombinant vaccinia viruses expressing gp120/gp41 (Chakrabarti et al., Nature 320:535-537  
15 (1986); Earl et al., J. Virol. 64:2448-2451 (1990)) and labeled with  $^{51}\text{Cr}$ . The labeled cells are incubated with cells from a human allospecific ( $\text{CD8}^+$ ,  $\text{CD4}^-$ ) cytotoxic T lymphocyte line which has been infected with vaccinia recombinants expressing the CD4-tyrosine kinase chimera,  
20 and examined to specific lysis.

To control for the possibility that vaccinia infection might promote artefactual recognition by CTL, similar cytolysis experiments are performed with target cells infected with vaccinia recombinants expressing the  
25 phosphatidylinositol linked form of CD16 ( $\text{CD16}_{\text{PI}}$ ) and labeled with  $^{51}\text{Cr}$ , and with CTL infected with control recombinants expressing CD16 chimeras.

In another example, neutrophilic granulocytes, which have a very short lifespan ( $\approx 4\text{h}$ ) in circulation  
30 and are intensely cytolytic, are attractive cells for expression of CD4-tyrosine kinase chimeras. Infection of neutrophils with HIV is not likely to result in virus release, and the abundance of these cells (the most prevalent of the leukocytes) should facilitate host  
35 defense. Another attractive possibility for host cells

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are mature T cells, a population presently accessible to retroviral engineering (Rosenberg, Sci. Am. 262:62-69 (1990)). With the aid of recombinant IL-2, T cell populations can be expanded in culture with relative ease, and the expanded populations typically have a limited lifespan when reinfused (Rosenberg et al., N. Engl. J. Med., 323:570-578 (1990)).

Under the appropriate conditions, HIV recognition by cells expressing CD4 chimeras should also provide mitogenic stimuli, allowing the possibility that the armed cell population could respond dynamically to the viral burden. Although we have focused here on the behavior of the fusion proteins in cytolytic T lymphocytes, expression of the chimeras in helper lymphocytes might provide an HIV-mobilized source of cytokines which could counteract the collapse of the helper cell subset in AIDS. Recent description of several schemes for engineering resistance to infection at steps other than virus penetration (Friedman et al., Nature 335:452-454 (1988); Green et al., Cell 58:215-223 (1989); Malim et al., Cell 58:205-214 (1989); Trono et al., Cell 59:113-120 (1989); Buonocore et al., Nature 345:625-628 (1990)) suggests that cells bearing CD4 chimeras could be designed to thwart virus production by expression of appropriate agents having an intracellular site of action.

The ability to transmit signals to T lymphocytes through autonomous chimeras also provides the ability for the regulation of retrovirally engineered lymphocytes in vivo. Crosslinking stimuli, mediated for example by specific IgM antibodies engineered to remove complement-binding domains, may allow such lymphocytes to increase in number in situ, while treatment with similar specific IgG antibodies (for example recognizing an amino acid variation engineered into the chimeric chain) could

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selectively deplete the engineered population. We have previously determined that anti-CD4 IgM antibodies do not require additional crosslinking to mobilize calcium in Jurkat cells expressing CD4:ζ chimeras. The ability to  
5 regulate cell populations without recourse to repeated extracorporeal amplification may substantially extend the range and efficacy of current uses proposed for genetically engineered T cells.

#### Combinatorial Control of Kinase Chimeras and CD28

##### 10 Chimeric Receptors

The demonstration that some kinase chimeras (such as ZAP-70 and Src family kinase chimeras) can function only in concert to direct cytolytic killing provides an opportunity to control the cytolytic response through the  
15 use of appropriate chimeric kinase pairs. This approach is particularly advantageous in the area of anti-tumor therapies because the extracellular domains of the chimera pairs can be designed to recognize and bind multiple determinants on tumor cell surfaces. Only upon  
20 the binding of each of the multiple determinants (and thus upon the involvement, for example, of the ZAP-70 and Src family kinases) is a potent cytolytic response effected. This approach increases therapeutic specificity by decreasing the likelihood and frequency of  
25 destruction of non-cancerous cells.

In one particular example, a pair of chimeras may include two different extracellular domains, each recognizing a distinct antigen characteristic of a targeted tumor. Such a pair of chimeras may recognize  
30 two unrelated molecules on the tumor surface (for example, two distinct proteinaceous cell surface markers), or the pair may recognize two different attributes of the same molecule (for example, an antigenic protein and an antigenic carbohydrate



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associated with the same cell surface protein). Examples of tumor antigens include, without limitation, any of a number of carbohydrates (e.g., Le<sup>Y</sup>, sialyl-Le<sup>Y</sup>, Le<sup>x</sup>, and sialyl-Le<sup>x</sup>), carcinoembryonic antigen, CD40, modified  
5 CD44,  $\alpha$ -fetoprotein, the T and Tn antigens, tenascin, and growth factor receptors (e.g., HER2/neu).

Moreover, because T cell activation has been shown to be augmented by engagement of CD28, the invention also includes therapeutic cells expressing sets of chimeric  
10 receptors, one of which includes the intracellular domain of CD28 and a second (or more) of which includes any protein-tyrosine kinase intracellular domain described herein. In a given set of chimeric receptors, the extracellular domains may be identical (for example, all  
15 may be derived from the CD4 protein and hence all recognize HIV or an HIV-infected cell), or, as discussed above, each may be designed to recognize a different target molecule on the surface of a cell or pathogen.

This method of combinatorial control can be  
20 extended to any number of cooperating chimeric receptors (for example, it may be used with combinations of ZAP-70 and Src family kinase chimeras or, alternatively, it may be used with a combination of a CD28 chimera, a ZAP-70 chimera, and a Src family kinase chimera to facilitate  
25 further combinatorial control). Moreover, it may be used to regulate any therapeutic method of the invention.

CD28 chimeras are constructed and expressed according to the methods described herein. The CD28 sequence is provided in Aruffo and Seed (Proc. Natl. Acad. Sci. USA 84:8573-8577 (1987)). Also included in  
30 this reference are descriptions of the CD28 intracellular and transmembrane domains. An example of a chimera bearing an intracellular CD28 domain is disclosed in Romeo et al. (Cold Spring Harbor Symp. on Quant. Biol.  
35 LVII:117-125 (1992)).

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Other Embodiments

To create other chimeras consisting of protein kinase intracellular sequences, cDNA or genomic sequences encoding an extracellular domain of the receptor can be  
5 endowed with a restriction site introduced at a location just preceding the extracellular domain of choice. The extracellular domain fragment terminating in the restriction site can then be joined to the protein kinase sequences. Typical extracellular domains may be derived  
10 from receptors which recognize complement, carbohydrates, viral proteins, bacteria, protozoan or metazoan parasites, or proteins induced by them. Similarly, ligands or receptors expressed by pathogens or tumor cells can be attached to protein kinase sequences to  
15 direct immune responses against cells bearing receptors recognizing those ligands.

To identify the minimal protein kinase sequences necessary for cytolysis, a series of deletion mutants may be prepared by standard techniques in which successively  
20 more of the kinase intracellular domain is removed. Such deletion mutants are tested for efficacy in any of the assays described herein. Useful intracellular domains for the Syk protein kinase include, for example, amino acids 336-628 of the porcine Syk sequence and amino acids  
25 338-630 of the human Syk sequence. Useful intracellular domains for the Src family kinases include, for example, the SH2 and SH3 domains.

While the invention has been described in connection with specific embodiments thereof, it will be  
30 understood that it is capable of further modifications and this application is intended to cover variations, uses, or adaptations of the invention and including such departures from the present disclosure as come within the art to which the invention pertains and as may be applied

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to the essential features hereinbefore set forth as follows in the scope of the appended claims.

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## SEQUENCE LISTING

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(i) APPLICANT: Brian Seed  
Charles Romeo  
Waldemar Kolanus

(ii) TITLE OF INVENTION: REDIRECTION OF CELLULAR IMMUNITY BY  
PROTEIN-TYROSINE KINASE CHIMERAS

(iii) NUMBER OF SEQUENCES: 9

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(A) MEDIUM TYPE: 3.5" Diskette, 1.44 Mb  
(B) COMPUTER: IBM PS/2 Model 50Z or 55SX  
(C) OPERATING SYSTEM: MS-DOS (Version 5.0)  
(D) SOFTWARE: WordPerfect (Version 5.1)

## (vi) CURRENT APPLICATION DATA:

(A) APPLICATION NUMBER: PCT/US96/-----  
(B) FILING DATE:

## (vii) PRIOR APPLICATION DATA:

(A) APPLICATION NUMBER: 08/394,177  
(B) FILING DATE: February 24, 1995

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## (2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 1:

## (i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 33  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 1:

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CGCGGGGTGA CCGTGCCCTC CAGCAGCTTG GGC

33

(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 2:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 50  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 2:

CGCGGGGATC CGTCGTCCAG AGCCCGTCCA GCTCCCCGTC CTGGGCCTCA

50

(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 3:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 33  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 3:

CGCGGGCGGC CGCGACGCCG GCCAAGACAG CAC

33

(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 4:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 33  
 (B) TYPE: nucleic acid  
 (C) STRANDEDNESS: single  
 (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 4:

CGCGTTGACG AGCAGCCAGT TGGGCAGCAG CAG

33

(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 5:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 630  
 (B) TYPE: amino acid  
 (C) STRANDEDNESS: N/A  
 (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 5:

Met	Ala	Asp	Ser	Ala	Asn	His	Leu	Pro	Phe	Phe	Phe	Gly	His	Ile	Thr
1				5					10				15		
Arg	Glu	Glu	Ala	Glu	Asp	Tyr	Leu	Val	Gln	Gly	Gly	Met	Ser	Asp	Gly
		20					25					30			

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Leu Tyr Leu Leu Arg Gln Ser Arg Asn Tyr Leu Gly Gly Phe Ala Leu  
 35 40 45  
 Ser Val Ala His Gly Arg Lys Ala His Asn Tyr Thr Ile Glu Arg Glu  
 50 55 60  
 Leu Asn Gly Thr Tyr Ala Ile Ala Gly Gly Arg Thr His Ala Ser Pro  
 65 70 75 80  
 Ala Asp Leu Cys Asn Tyr His Ser Gln Glu Ser Asp Gly Leu Val Cys  
 85 90 95  
 Leu Leu Lys Lys Pro Phe Asn Arg Pro Gln Gly Val Gln Pro Lys Thr  
 100 105 110  
 Gly Pro Phe Glu Asp Leu Lys Glu Asn Leu Ile Arg Glu Tyr Val Lys  
 115 120 125  
 Gln Thr Met Asn Leu Gln Gly Gln Ala Leu Glu Gln Ala Ile Ile Ser  
 130 135 140  
 Gln Lys Pro Gln Leu Glu Lys Leu Ile Ala Thr Thr Ala His Glu Lys  
 145 150 155 160  
 Met Pro Trp Phe His Gly Lys Ile Ser Arg Glu Ile Ser Thr Gln Ile  
 165 170 175  
 Val Leu Ile Gly Ser Lys Thr Asn Gly Lys Phe Leu Ile Arg Ala Arg  
 180 185 190  
 Asp Asn Asn Gly Ser Tyr Ala Leu Cys Leu Leu His Ile Gly Lys Val  
 195 200 205  
 Leu His Tyr Arg Ile Asp Lys Asp Lys Thr Gly Lys Leu Ser Ile Pro  
 210 215 220  
 Glu Gly Lys Lys Phe Asp Thr Leu Trp Gln Leu Val Glu His Tyr Ser  
 225 230 235 240  
 Tyr Lys Ala Asp Gly Leu Leu Arg Val Leu Thr Val Pro Cys Gln Lys  
 245 250 255  
 Ile Gly Thr Gln Gly Asn Val Asn Phe Gly Gly Arg Pro Gln Leu Phe  
 260 265 270  
 Gly Ser His Pro Ala Thr His Ser Ala Gly Gly Ile Ile Ser Arg Ile  
 275 280 285  
 Lys Ser Tyr Ser Phe Pro Lys Pro Gly His Arg Lys Ser Ser Pro Ala  
 290 295 300  
 Gln Gly Asn Arg Gln Glu Ser Thr Val Ser Phe Asn Phe Tyr Glu Pro  
 305 310 315 320  
 Glu Leu Ala Pro His Ala Ala Asp Lys Gly Pro Gln Arg Ile Ala Leu  
 325 330 335  
 Pro Met Asp Thr Glu Val Tyr Glu Ser Pro Tyr Ala Asp Pro Glu Glu  
 340 345 350  
 Ile Arg Pro Lys Glu Val Tyr Leu Asp Arg Lys Leu Leu Thr Leu Glu  
 355 360 365  
 Asp Lys Glu Leu Gly Ser Gly Asn Phe Gly Thr Val Lys Lys Gly Tyr  
 370 375 380  
 Tyr Gln Met Lys Lys Val Val Lys Thr Val Ala Val Lys Ile Leu Lys  
 385 390 395 400  
 Asn Glu Ala Asn Asp Pro Ala Leu Lys Asp Glu Leu Leu Ala Glu Ala  
 405 410 415  
 Asn Val Met Gln Gln Leu Asp Asn Pro Tyr Ile Val Arg Met Ile Gly  
 420 425 430  
 Ile Cys Glu Ala Glu Ser Trp Met Leu Val Met Glu Met Ala Glu Leu  
 435 440 445  
 Gly Pro Leu Asn Lys Tyr Leu Gln Gln Asn Arg His Val Lys Leu Lys  
 450 455 460  
 Asn Ile Ile Glu Leu Val His Gln Val Ser Met Gly Met Lys Tyr Leu  
 465 470 475 480  
 Glu Glu Ser Asn Phe Val His Arg Asp Leu Ala Ala Arg Asn Val Leu  
 485 490 495  
 Leu Val Thr Gln His Tyr Ala Lys Ile Ser Asp Phe Gly Leu Ser Lys  
 500 505 510  
 Ala Leu Arg Ala Asp Glu Asn Tyr Tyr Lys Ala Gln Thr His Gly Lys  
 515 520 525

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Trp Pro Val Lys Trp Tyr Ala Pro Glu Cys Ile Asn Tyr Tyr Lys Phe
   530           535           540
Ser Ser Lys Ser Asp Val His Ser Phe Gly Val Leu Met Asn Glu Ala
545           550           555           560
Phe Ser Tyr Gly Gln Lys Phe Tyr Arg Gly Met Lys Gly Ser Glu Val
           565           570           575
Ile Ala Met Leu Glu Lys Gly Glu Arg Met Gly Cys Pro Ala Gln Cys
           580           585           590
Pro Arg Glu Met Tyr Asp Leu Met Asn Leu Cys Trp Thr Tyr Asp Val
           595           600           605
Glu Asn Arg Pro Gly Phe Ala Ala Val Glu Leu Arg Leu Arg Asn Tyr
610           615           620
Tyr Tyr Asp Val Val Asn
625           630

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(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 6:

## (i) SEQUENCE CHARACTERISTICS:

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(A) LENGTH:      628
(B) TYPE: amino acid
(C) STRANDEDNESS: N/A
(D) TOPOLOGY: linear

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## (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 6:

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Met Ala Asp Ser Ala Asn His Leu Pro Phe Phe Phe Gly Gln Ile Thr
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Arg Glu Glu Ala Glu Asp Tyr Leu Val Gln Gly Gly Met Ser Asp Gly
           20           25           30
Leu Tyr Leu Leu Arg Gln Ser Arg Asn Tyr Leu Gly Gly Phe Ala Leu
           35           40           45
Ser Val Ala Tyr Asp Arg Lys Ala His His Tyr Thr Ile Glu Arg Glu
50           55           60
Leu Asn Gly Thr Tyr Ala Ile Ser Gly Gly Arg Thr His Gly Ser Pro
65           70           75           80
Ala Glu Leu Cys His Tyr His Ser Gln Glu Leu Asp Gly Leu Val Cys
           85           90           95
Leu Leu Lys Asn Pro Phe Asn Arg Pro Pro Gly Val Gln Pro Lys Thr
           100           105           110
Gly Pro Phe Glu Asp Leu Lys Glu Asn Leu Ile Arg Glu Tyr Val Lys
           115           120           125
Gln Thr His Asn Leu Gln Gly Gln Ala Leu Glu Gln Ala Ile Ile Ser
130           135           140
Gln Lys Pro Gln Leu Glu Lys Leu Ile Ala Thr Thr Ala His Glu Lys
145           150           155           160
Met Pro Trp Phe His Gly Lys Ile Ser Arg Asp Glu Ser Glu Gln Ile
           165           170           175
Val Leu Ile Gly Ser Lys Ile Asn Gly Lys Phe Leu Ile Arg Ala Arg
           180           185           190
Asp Met Gly Ser Tyr Ala Leu Gly Leu Leu His Ile Gly Lys Val Leu
195           200           205
Met Tyr Arg Ile Asp Lys Asp Lys Thr Gly Lys Leu Ser Ile Pro Gly
210           215           220
Gly Lys Asn Phe Asp Thr Leu Trp Gln Leu Val Glu Lys Tyr Ser Tyr
225           230           235           240
Lys Ser Asp Gly Leu Leu Arg Val Leu Thr Val Pro Cys Gln Lys Ile
           245           250           255
Gly Gly Gln Thr Gly Asn Asp Ser Phe Arg Pro Gln Leu Phe Ser Ala
260           265           270
His Ser Ala Thr Trp Ser Ala Gly Gly Ile Ile Ser Arg Ile Lys Ser
275           280           285

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Tyr Ser Phe Pro Lys Pro Gly His Arg Lys Ala Ser Ser Pro Gln Gly  
 290 295 300  
 Asn Arg Pro Glu Ser Leu Val Ser Tyr Asn Phe Tyr Glu Ser Asp Arg  
 305 310 315 320  
 Gly Phe Trp Ala Asn Glu Arg Glu Ala Gln Arg Glu Ala Leu Pro Met  
 325 330 335  
 Asp Thr Glu Val Val Glu Ser Pro Tyr Ala Asp Pro Glu Glu Ile Arg  
 340 345 350  
 Pro Lys Glu Val Tyr Leu Asp Arg Lys Leu Leu Thr Leu Glu Asp Lys  
 355 360 365  
 Glu Leu Gly Ser Gly Asn Phe Gly Thr Val Lys Lys Gly Tyr Tyr Gln  
 370 375 380  
 Met Lys Lys Val Val Lys Thr Val Ala Val Lys Ile Leu Lys Asn Glu  
 385 390 395 400  
 Ala Asn Asp Pro Ala Leu Lys Asp Glu Leu Leu Ala Glu Ala Asn Val  
 405 410 415  
 Met Gln Gln Leu Asp Asn Pro Tyr Ile Val Arg Met Ile Gly Ile Cys  
 420 425 430  
 Glu Ala Ser Ser Trp Met Leu Val Met Glu Met Ala Glu Leu Gly Pro  
 435 440 445  
 Leu Asn Lys Tyr Leu Gln Gln Asn Arg His Val Lys Asp Lys Asn Ile  
 450 455 460  
 Ile Glu Leu Val His Gln Val Ser Met Gly Met Lys Tyr Leu Glu Glu  
 465 470 475 480  
 Cys Asn Pro Val His Arg Asp Leu Ala Ala Arg Asn Val Leu Leu Val  
 485 490 495  
 Thr Gln His Tyr Ala Lys Ile Ser Asp Phe Gly Leu Ser Lys Ala Leu  
 500 505 510  
 Arg Ala Asp Glu Asn Tyr Tyr Lys Ala Gln Thr His Gly Lys Trp Pro  
 515 520 525  
 Val Lys Trp Tyr Ala Pro Glu Cys Ile Asn Tyr Tyr Lys Phe Ser Ser  
 530 535 540  
 Lys Ser Asp Val Asn Ser Phe Gly Val Leu Met Trp Glu Ala Phe Ser  
 545 550 555 560  
 Tyr Gly Gln Lys Phe Tyr Arg Gly Met Lys Gly Ser Glu Val Ser Ala  
 565 570 575  
 Met Leu Glu Lys Gly Glu Arg Met Gly Cys Phe Phe Gly Cys Phe Arg  
 580 585 590  
 Glu Met Tyr Glu Leu Asn Thr Leu Cys Asn Thr Tyr Asp Val Glu Asn  
 595 600 605  
 Arg Pro Gly Phe Val Ala Val Glu Leu Arg Leu Arg Asn Tyr Tyr Tyr  
 610 615 620  
 Asp Val Val Asn  
 625

(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 7:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 34
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 7:

ATGGCAGACA GTGCCAACCA CTTGCCCTTC TTCT

34

(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 8:

(i) SEQUENCE CHARACTERISTICS:



- 71 -

(A) LENGTH: 39  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 8:

CGCGGGGCGG CCGCTTTAAT TCACCACGTC GTAGTAGTA

39

(2) INFORMATION FOR SEQUENCE IDENTIFICATION NUMBER: 9:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 33  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 9:

CGCGGGACGC GTACCATGGC AGACAGTGCC AAC

33

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Claims

1. A method of directing a cellular immune response in a mammal, said method comprising administering to said mammal an effective amount of  
5 therapeutic cells, each of said therapeutic cells expressing a membrane-bound, proteinaceous chimeric receptor, comprising (a) an intracellular portion of a protein-tyrosine kinase which is capable of signalling said therapeutic cell to destroy a receptor-bound target  
10 cell or a receptor-bound target infective agent and (b) an extracellular portion which is capable of specifically recognizing and binding said target cell or said target infective agent, whereby each of said therapeutic cells is capable of specifically recognizing and destroying  
15 said target cell or target infective agent.
2. The method of claim 1, wherein said target cell is a host cell infected with an infective agent, a tumor or cancerous cell, or an autoimmune-generated cell.
3. The method of claim 1, wherein said protein-  
20 tyrosine kinase is a member of the Syk kinase family.
4. The method of claim 3, wherein said protein-tyrosine kinase is Syk.
5. The method of claim 4, wherein said  
intracellular portion includes human Syk amino acids 336-  
25 628 or porcine Syk amino acids 338-630.
6. The method of claim 1, wherein each of said therapeutic cells expresses a second membrane-bound, proteinaceous chimeric receptor, said second chimeric receptor comprising (a) an intracellular portion of a  
30 second protein-tyrosine kinase which is capable of

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signalling said therapeutic cell to destroy a receptor-bound target cell or a receptor-bound target infective agent and (b) an extracellular portion which is capable of specifically recognizing and binding said target cell  
5 or said target infective agent, whereby each of said therapeutic cells is capable of specifically recognizing and destroying said target cell or target infective agent.

7. The method of claim 6, wherein one of said  
10 protein-tyrosine kinases is a member of the Syk kinase family and the other of said protein-tyrosine kinases is a member of the Src kinase family.

8. The method of claim 6, wherein one of said  
protein-tyrosine kinases is ZAP-70 and the other of said  
15 protein-tyrosine kinases is Fyn.

9. The method of claim 6, wherein one of said  
protein-tyrosine kinases is ZAP-70 and the other of said  
protein-tyrosine kinases is Lck.

10. The method of claims 8 or 9, wherein said  
20 ZAP-70 portion includes human ZAP-70 Tyr 369.

11. The method of claims 1 or 6, wherein said  
cellular response is MHC-independent.

12. The method of claims 1 or 6, wherein said  
therapeutic cells are selected from the group consisting  
25 of: (a) T lymphocytes; (b) cytotoxic T lymphocytes; (c)  
natural killer cells; (d) neutrophils; (e) granulocytes;  
(f) macrophages; (g) mast cells; (h) HeLa cells; and (i)  
embryonic stem cells (ES).

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13. The method of claim 1, wherein said target infective agent is an immunodeficiency virus.

14. The method of claim 13, wherein said extracellular portion comprises an HIV envelope-binding  
5 portion of CD4.

15. The method of claims 1 or 6, wherein said therapeutic cells further express a membrane-bound, proteinaceous chimeric receptor comprising (a) an extracellular portion which is capable of specifically  
10 recognizing and binding said target cell or said target infective agent, and (b) an intracellular portion which is derived from CD28.

16. The method of claim 1, wherein said therapeutic cells destroy said receptor-bound target cell  
15 or target infective agent by cytolysis.

17. A cell which expresses a membrane-bound, proteinaceous chimeric receptor, comprising (a) an intracellular portion of a protein-tyrosine kinase which is capable of signalling said therapeutic cell to destroy  
20 a receptor-bound target cell or a receptor-bound target infective agent and (b) an extracellular portion which is capable of specifically recognizing and binding said target cell or said target infective agent, whereby each  
25 of said therapeutic cells is capable of specifically recognizing and destroying said target cell or target infective agent.

18. The cell of claim 17, wherein said protein-tyrosine kinase is a member of the Syk kinase family.

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19. The cell of claim 18, wherein said protein-tyrosine kinase is Syk.

20. The cell of claim 19, wherein said intracellular portion includes human Syk amino acids 336-  
5 628 or porcine Syk amino acids 338-630.

21. The cell of claim 17, wherein each of said therapeutic cells expresses a second membrane-bound, proteinaceous chimeric receptor, said second chimeric receptor comprising (a) an intracellular portion of a  
10 second protein-tyrosine kinase which is capable of signalling said therapeutic cell to destroy a receptor-bound target cell or a receptor-bound target infective agent and (b) an extracellular portion which is capable  
15 of specifically recognizing and binding said target cell or said target infective agent, whereby each of said therapeutic cells is capable of specifically recognizing and destroying a target cell or target infective agent.

22. The cell of claim 21, wherein one of said protein-tyrosine kinases is a member of the Syk kinase  
20 family and the other of said protein-tyrosine kinases is a member of the Src kinase family.

23. The cell of claim 21, wherein one of said protein-tyrosine kinases is ZAP-70 and the other of said protein-tyrosine kinases is Fyn.

25 24. The cell of claim 21, wherein one of said protein-tyrosine kinases is ZAP-70 and the other of said protein-tyrosine kinases is Lck.

25. The cell of claims 23 or 24, wherein said ZAP-70 portion includes human ZAP-70 Tyr 369.

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26. The cell of claims 17 or 21, wherein said therapeutic cells are selected from the group consisting of: (a) T lymphocytes; (b) cytotoxic T lymphocytes; (c) natural killer cells; (d) neutrophils; (e) granulocytes;  
5 (f) macrophages; (g) mast cells; (h) HeLa cells; and (i) embryonic stem cells (ES).

27. The cell of claim 17, wherein said target infective agent is an immunodeficiency virus.

28. The cell of claim 27, wherein said  
10 extracellular portion comprises an HIV envelope-binding portion of CD4.

29. The cell of claims 17 or 21, wherein said therapeutic cells further express a membrane-bound, proteinaceous chimeric receptor comprising (a) an  
15 extracellular portion which is capable of specifically recognizing and binding said target cell or said target infective agent, and (b) an intracellular portion which is derived from CD28.

30. The cell of claim 17, wherein said  
20 therapeutic cells destroy said receptor-bound target cell or target infective agent by cytolysis.

31. The cell of claims 17 or 21, wherein said binding is MHC-independent.

32. The cell of claims 17 or 21, wherein said  
25 extracellular portion comprises the ligand-binding portion of a receptor, the receptor-binding portion of a ligand, the antigen-binding portion of an antibody, or a functional derivative thereof.

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33. A cell which expresses a membrane-bound, proteinaceous chimeric receptor comprising (a) an intracellular portion of a protein-tyrosine kinase and (b) an extracellular portion which is capable of specifically recognizing and binding a target cell or target infective agent.

34. The cell of claim 33, wherein said protein-tyrosine kinase is chosen from a member of the Syk family.

10 35. The cell of claim 33, wherein said protein-tyrosine kinase is chosen from a member of the Src family.

36. The cell of claim 33, wherein said protein-tyrosine kinase is chosen from Syk, ZAP-70, Fyn, and Lck.

15 37. DNA encoding a chimeric receptor encoding a membrane-bound, proteinaceous chimeric receptor, comprising (a) an intracellular portion of a protein-tyrosine kinase which is capable of signalling said therapeutic cell to destroy a receptor-bound target cell or a receptor-bound target infective agent and (b) an extracellular portion which is capable of specifically recognizing and binding said target cell or said target infective agent, whereby each of said therapeutic cells is capable of specifically recognizing and destroying said target cell or target infective agent.

20

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38. DNA encoding a membrane-bound, proteinaceous chimeric receptor comprising (a) an intracellular portion of a protein-tyrosine kinase and (b) an extracellular portion which is capable of specifically recognizing and binding a target cell or target infective agent.

30

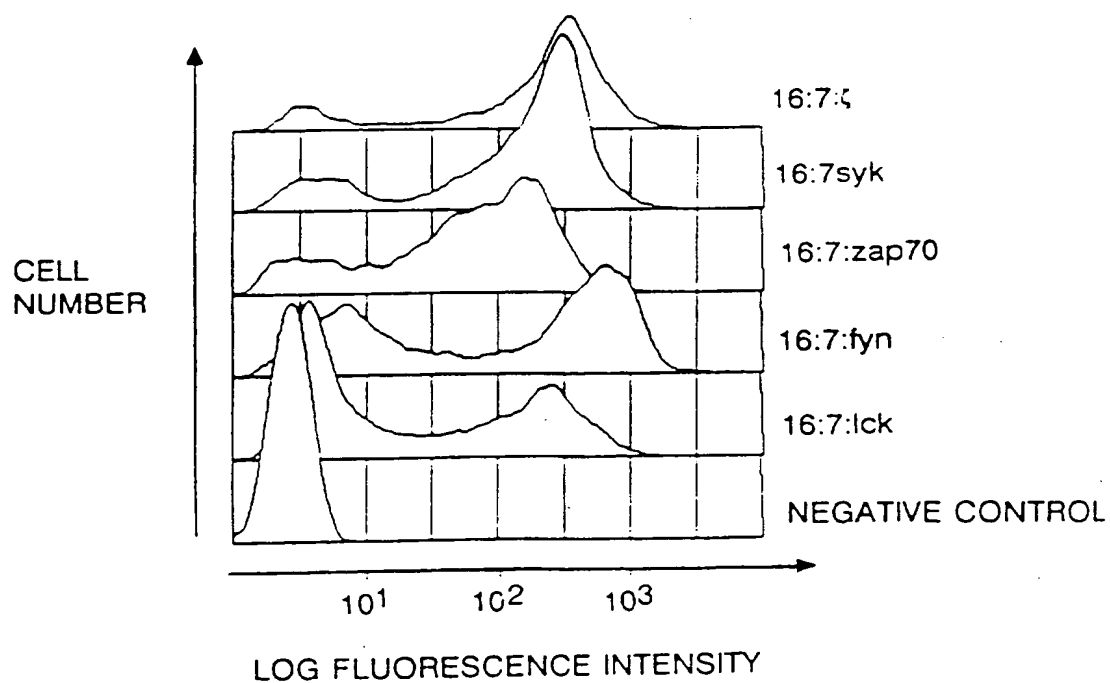
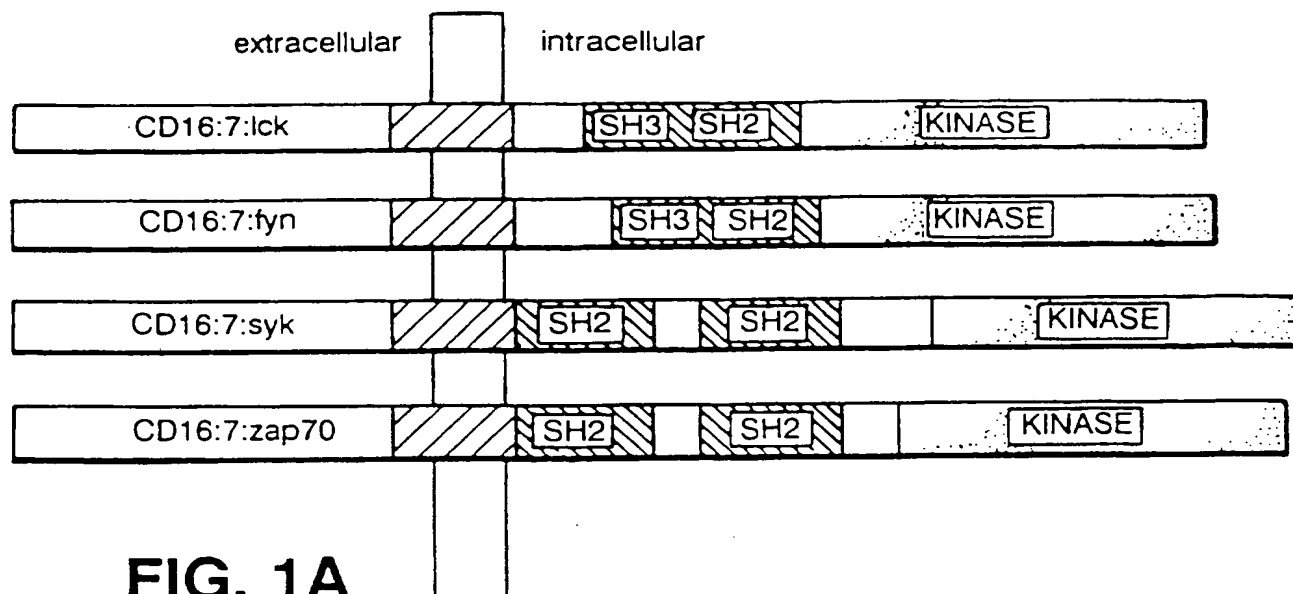
- 78 -

39. A vector comprising the chimeric receptor DNA of claim 37.

40. A vector comprising the chimeric receptor DNA of claim 38.



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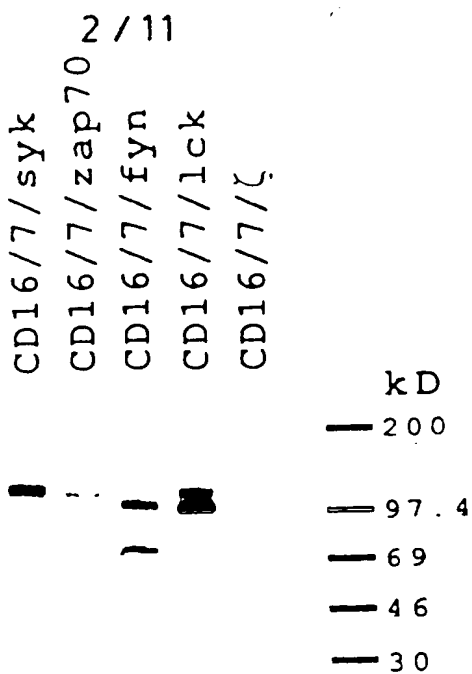


FIG. 1C

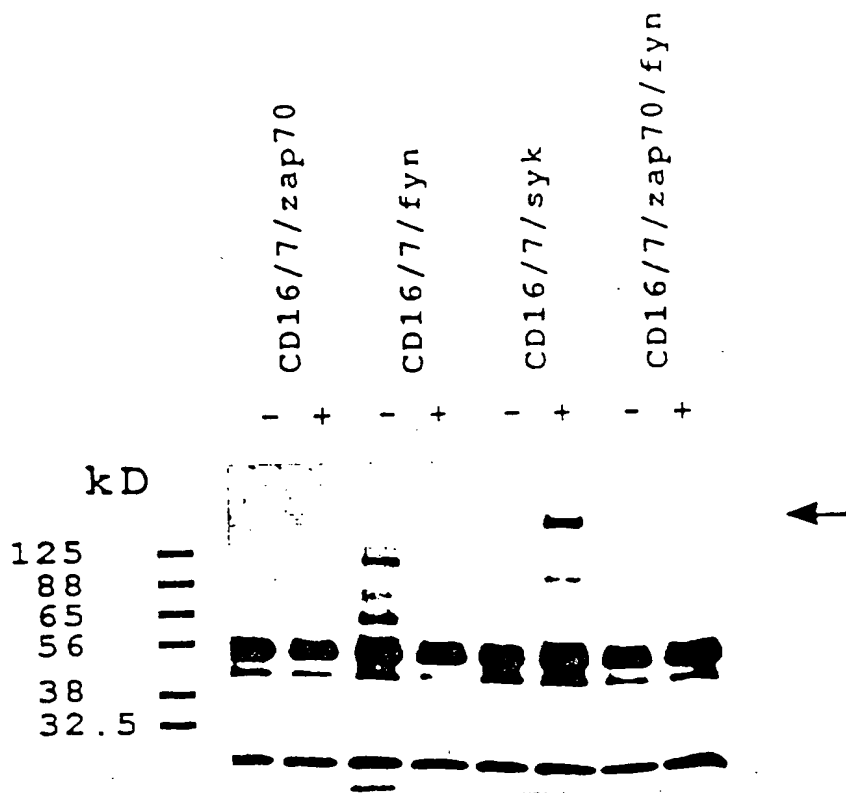


FIG. 9

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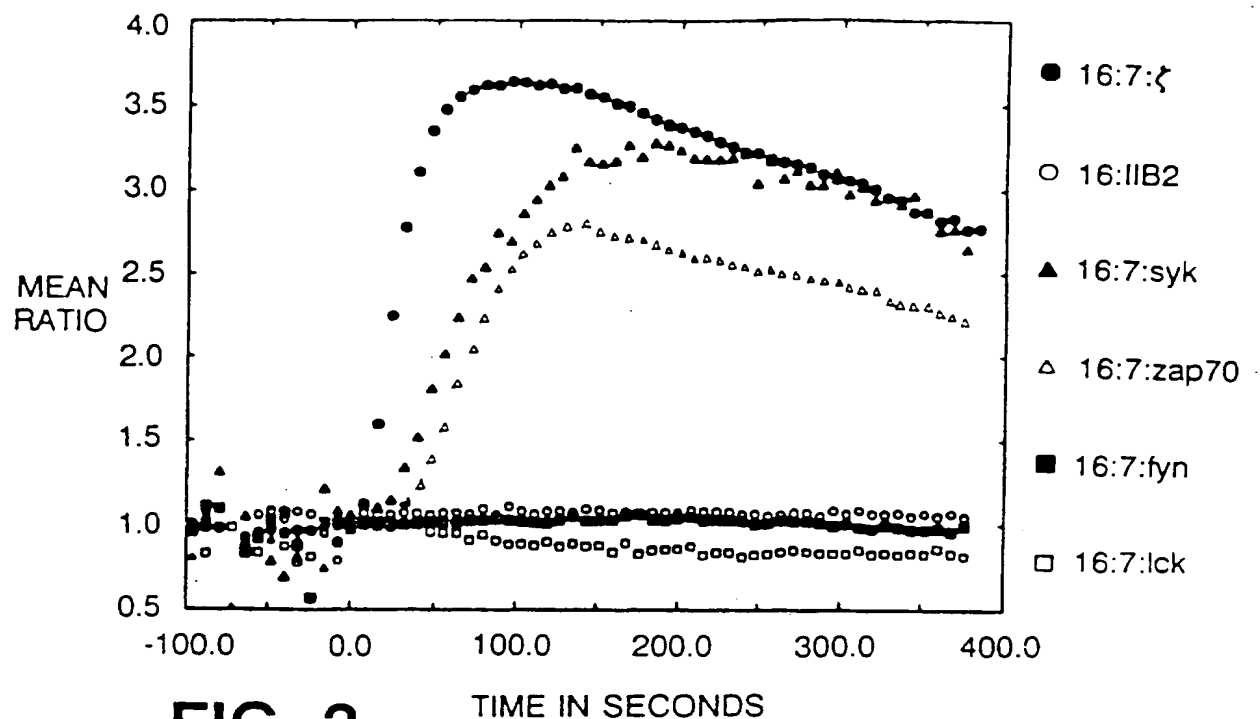


FIG. 2

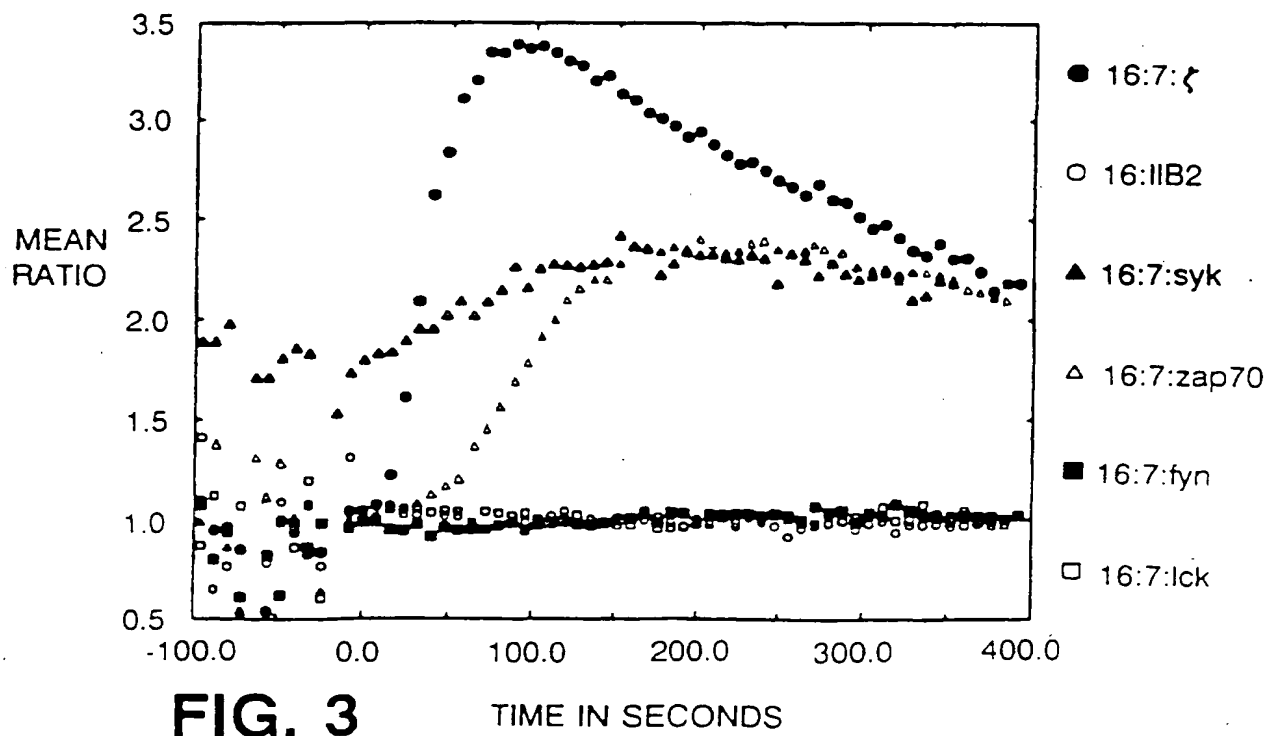


FIG. 3

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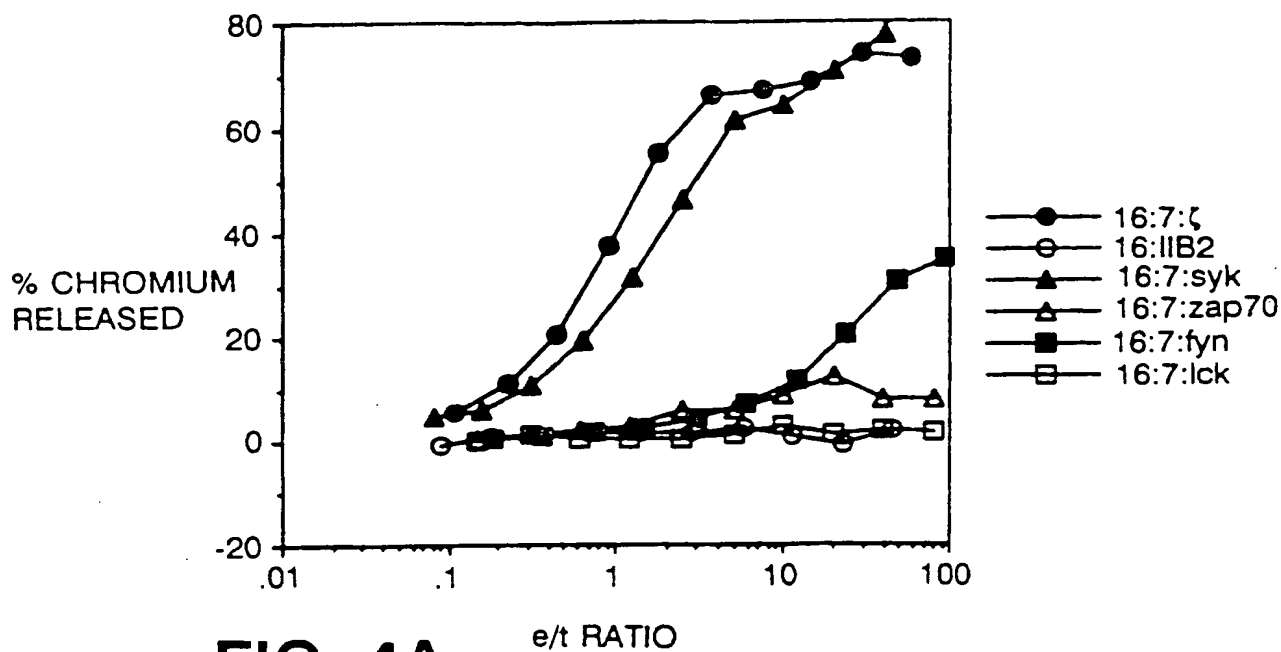


FIG. 4A

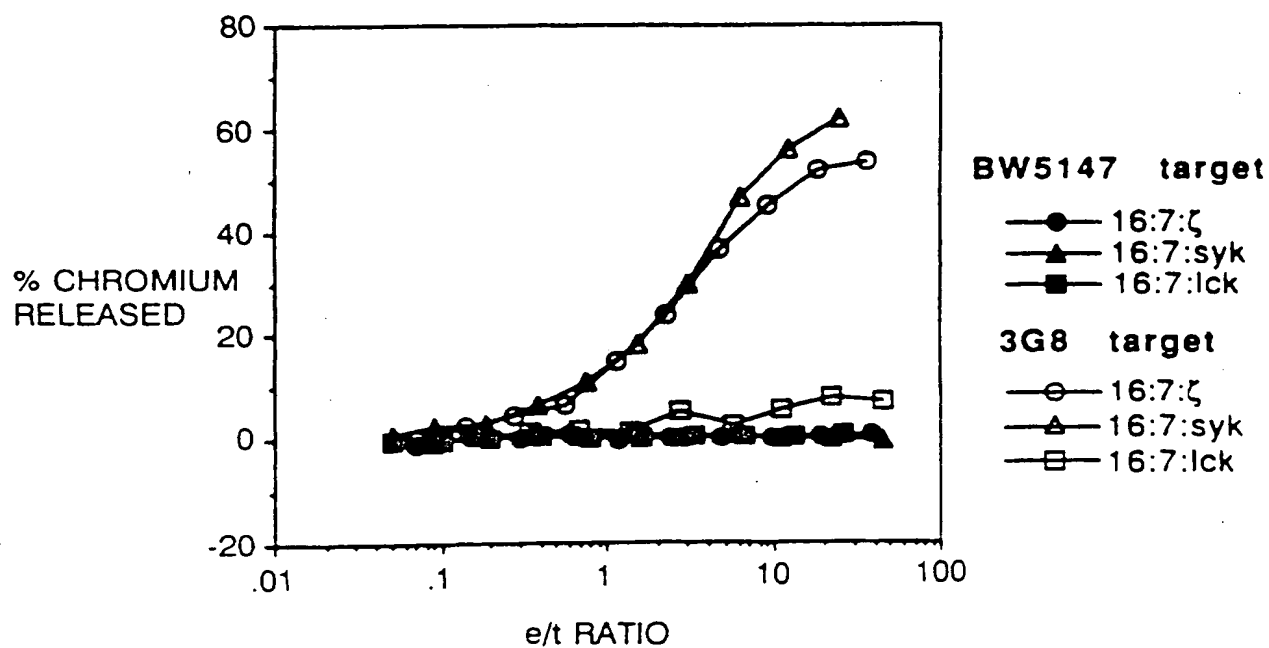
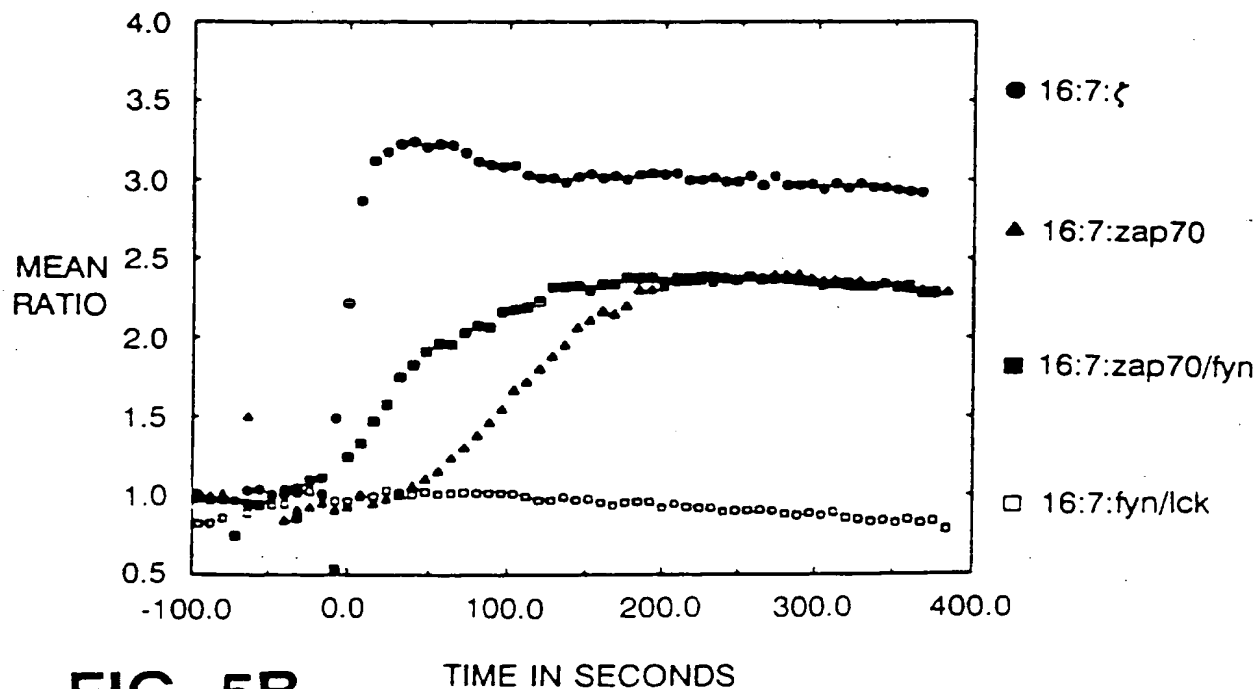
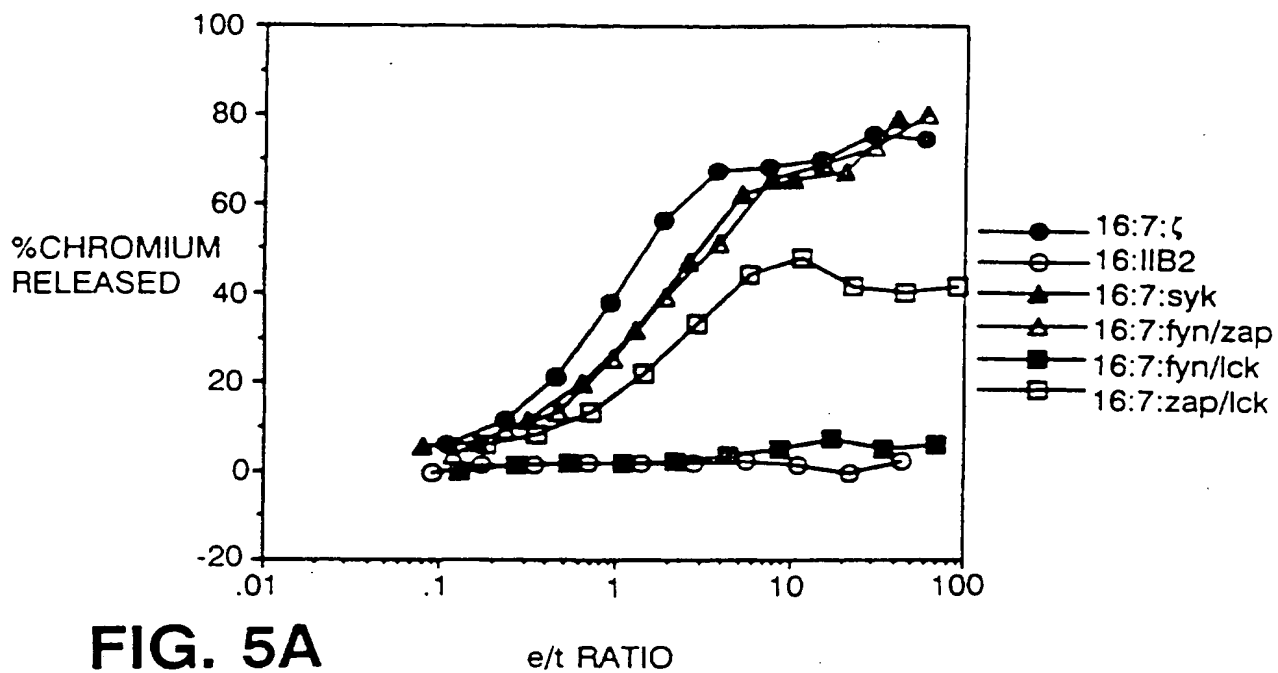
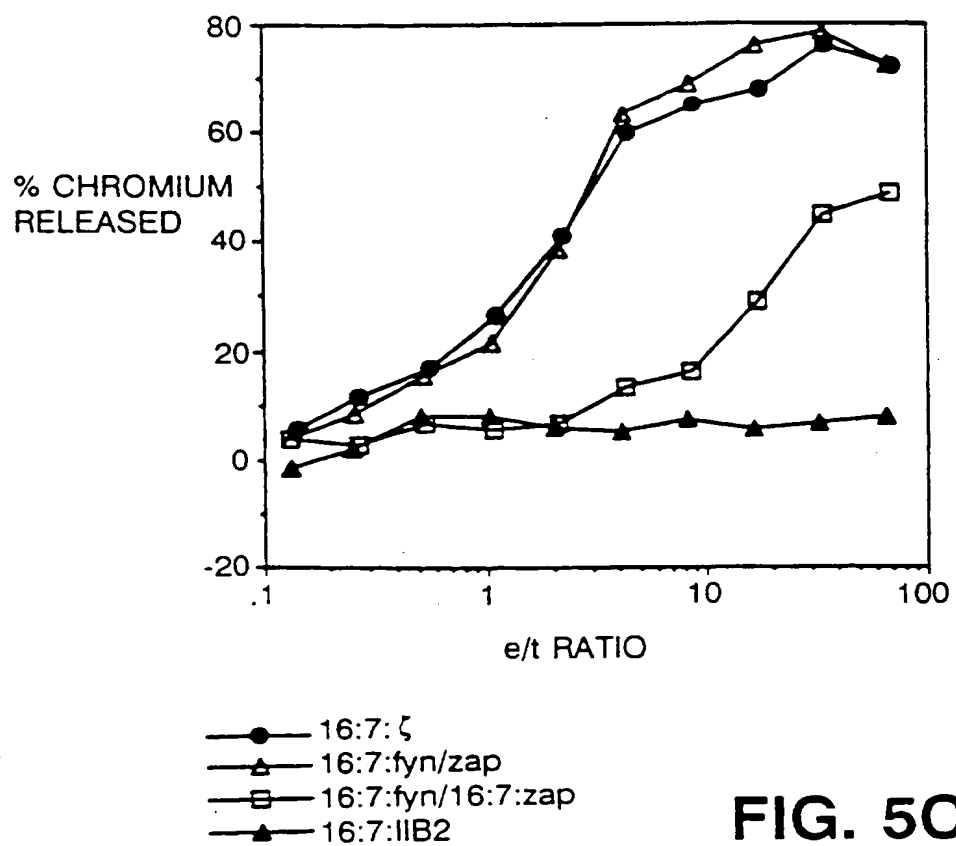


FIG. 4B

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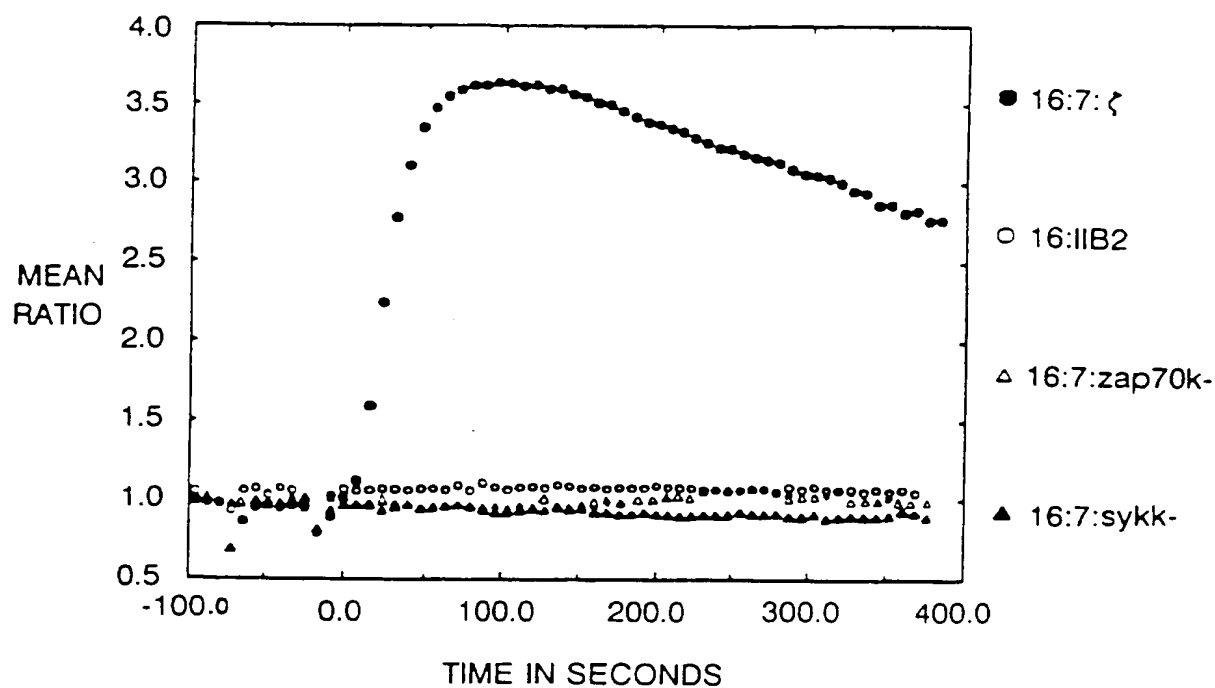


FIG. 6A

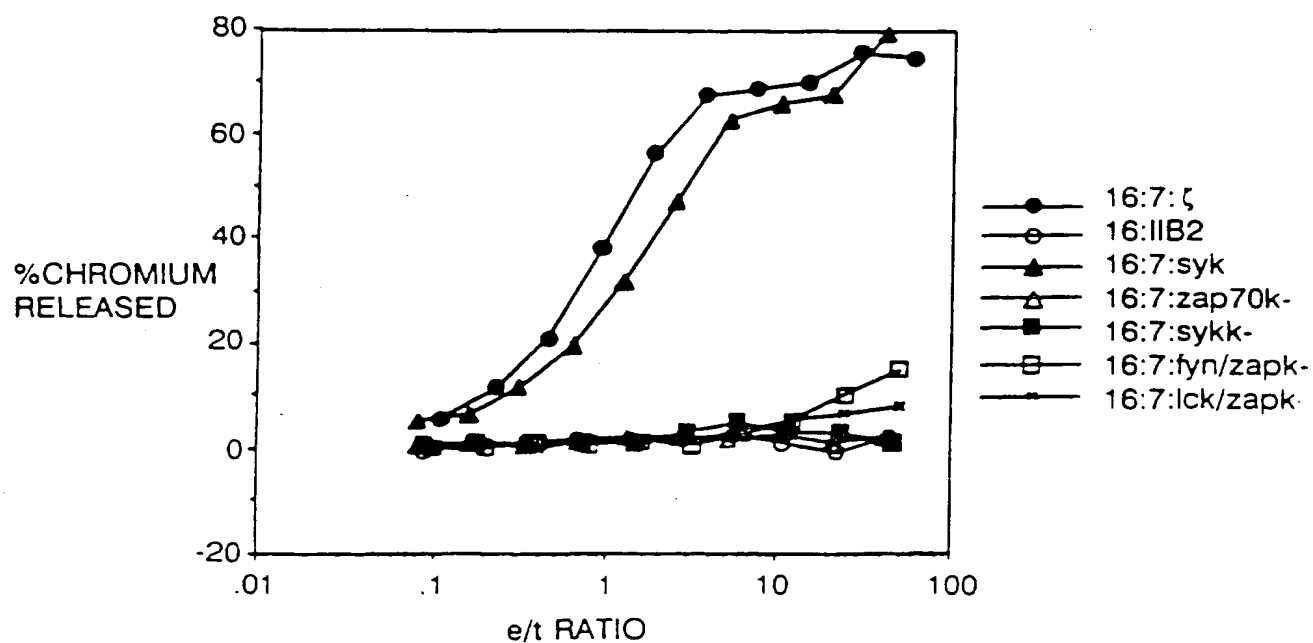


FIG. 6B

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human 1 MADSANHLPPFFFGNITREEAEDYLVQGGMSDGLYLLRQSRNYLGGFALS<sup>50</sup>  
 |||||  
 porcine 1 MADSANHLPPFFFGQITREEAEDYLVQGGMSDGLYLLRQSRNYLGGFALS<sup>50</sup>  
 |||||  
 51 AHGRKAHHTIERELNGTYAIAAGGRTHASPADLCHYHSQESDGLVCLLK<sup>100</sup>  
 |: |||||  
 51 AYDRKAHHTIERELNGTYAISGGRTHGSPAELCHYHSQELDGLVCLLK<sup>100</sup>  
 |||||  
 101 PFNRPGVQPKTGPFEDLKENLIREYVKOTWNLOGQALEQAIISQKPQLE<sup>150</sup>  
 |||||  
 101 PFNRPPGVQPKTGPFEDLKENLIREYVKOTWNLOGQALEQAIISQKPQLE<sup>150</sup>  
 |||||  
 151 KLIATTAHEKMPWFHGKISREESEQIVLIGSKTNGKFLIRARDNNGSYAL<sup>200</sup>  
 |||||  
 151 KLIATTAHEKMPWFHGKISRDESEQIVLIGSKTNGKFLIRARD.NGSYAL<sup>199</sup>  
 |||||  
 201 CLLHEGKVLHYRIDKDKTGKLSIPEGKKFDTLWQVLEHYSYKADGLLRVL<sup>250</sup>  
 |||||  
 200 GLLHEGKVLHYRIDKDKTGKLSIPGGKNFDTLWQVLEHYSYKSDGLLRVL<sup>249</sup>  
 |||||  
 251 TVPCQKIGTQ.GNVNFGGRPQLPGSHPATWSAGGIISRIKSYSFPKPGHR<sup>299</sup>  
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 250 TVPCQKIGGQTGNDSE..RPQLPSAHPATWSAGGIISRIKSYSFPKPGHR<sup>297</sup>  
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 300 KSSPAQGNRQESTVSFNPEPELAPWAADKGPQREALPMDTEVYESPYAD<sup>349</sup>  
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 298 KASSPQGNRPESLVSYNPEYSDRGPWANEREAQREALPMDTEVYESPYAD<sup>347</sup>  
 |||||  
 350 PEEIRPKEVYLDKLLTLEDKELGSGNFGTVKKGYQMKKVKTAVKIL<sup>399</sup>  
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 348 PEEIRPKEVYLDKLLTLEDKELGSGNFGTVKKGYQMKKVKTAVKIL<sup>397</sup>  
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 400 KNEANDPALKDELLAEANVMQQLDNPIYVRMIGICEAESWMLVMEAE<sup>449</sup>  
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 398 KNEANDPALKDELLAEANVMQQLDNPIYVRMIGICEAESWMLVMEAE<sup>447</sup>  
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 450 PLNKYLQQNRHVKDKNIIELVHQVSMGMKYLEESNPFVHRDLAARNVLLVT<sup>499</sup>  
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 448 PLNKYLQQNRHVKDKNIIELVHQVSMGMKYLEECNPFVHRDLAARNVLLVT<sup>497</sup>  
 |||||  
 500 QHYAKISDFGLSKALRADENYYKAQTHGKWPVKWYAPECINYYKFSSKSD<sup>549</sup>  
 |||||  
 498 QHYAKISDFGLSKALRADENYYKAQTHGKWPVKWYAPECINYYKFSSKSD<sup>547</sup>  
 |||||  
 550 VWSFGVLMWEAFSYGQKPYRGMKGSEVTAMLEKGERMGCPAGCPREMYDL<sup>599</sup>  
 |||||  
 548 VWSFGVLMWEAFSYGQKPYRGMKGSEVSAMLEKGERMGCPGCPREMYEL<sup>597</sup>  
 |||||  
 600 MNLCWPTYDVENRPGFAAVELRLRNYYYDVVN<sup>630</sup>  
 |||||  
 598 MTLWCWPTYDVENRPGFVAVELRLRNYYYDVVN<sup>628</sup>

FIG. 7A



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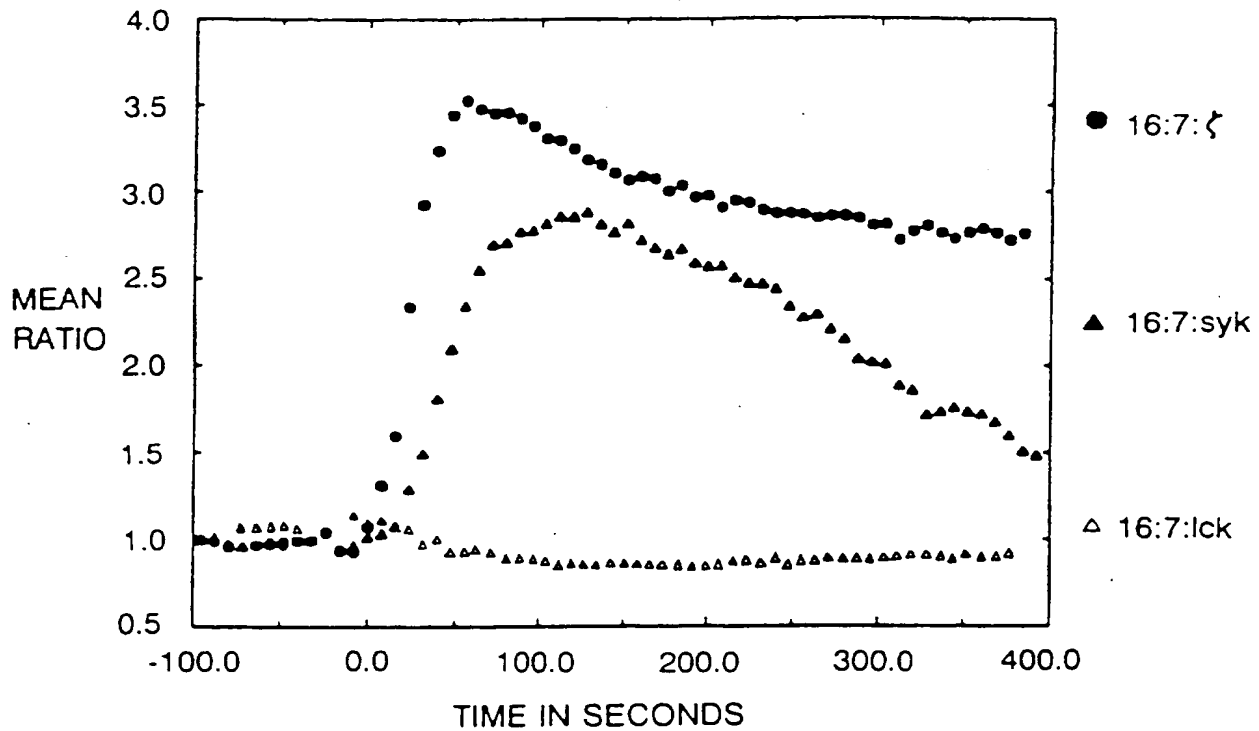


FIG. 7B

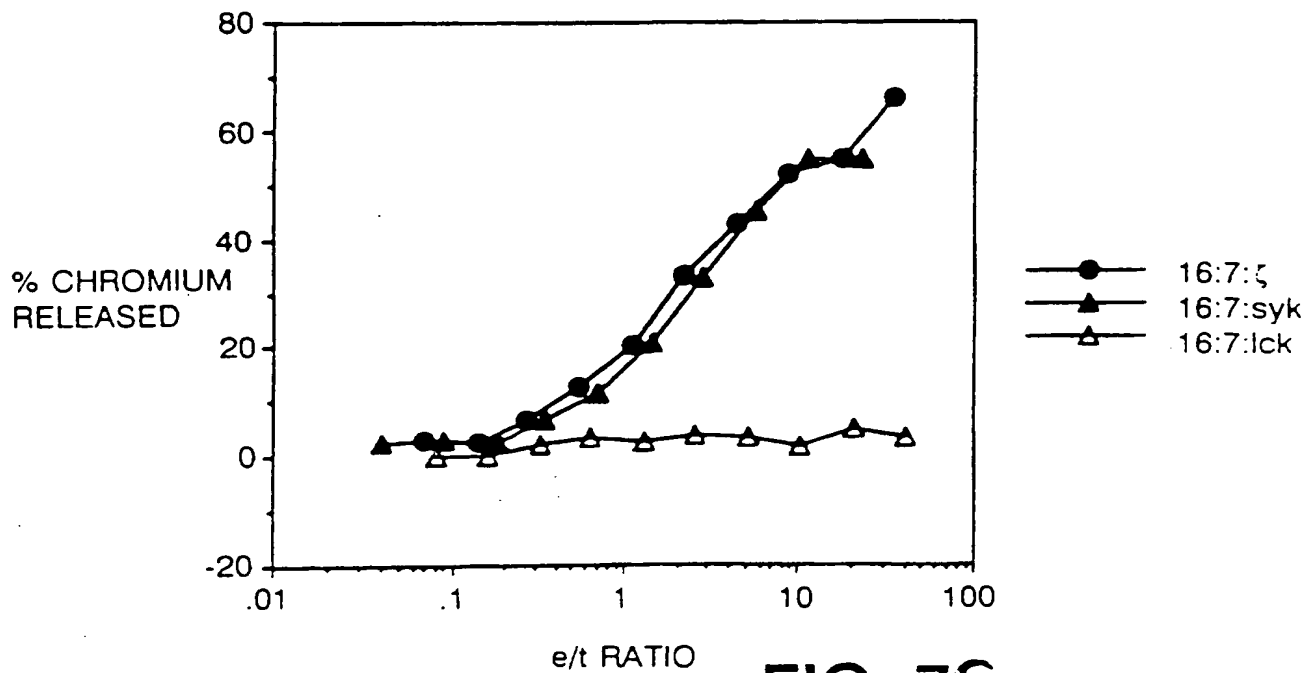


FIG. 7C

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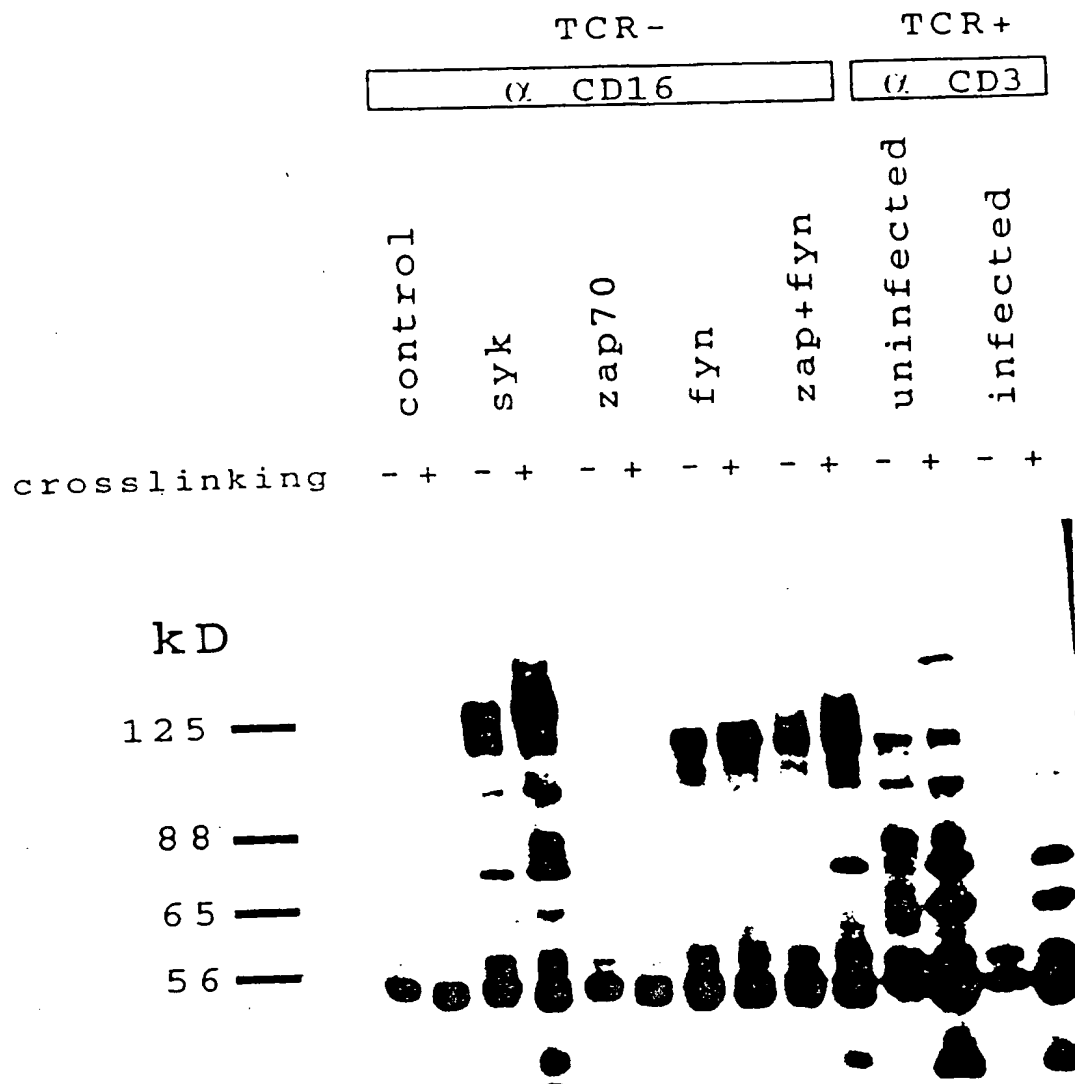
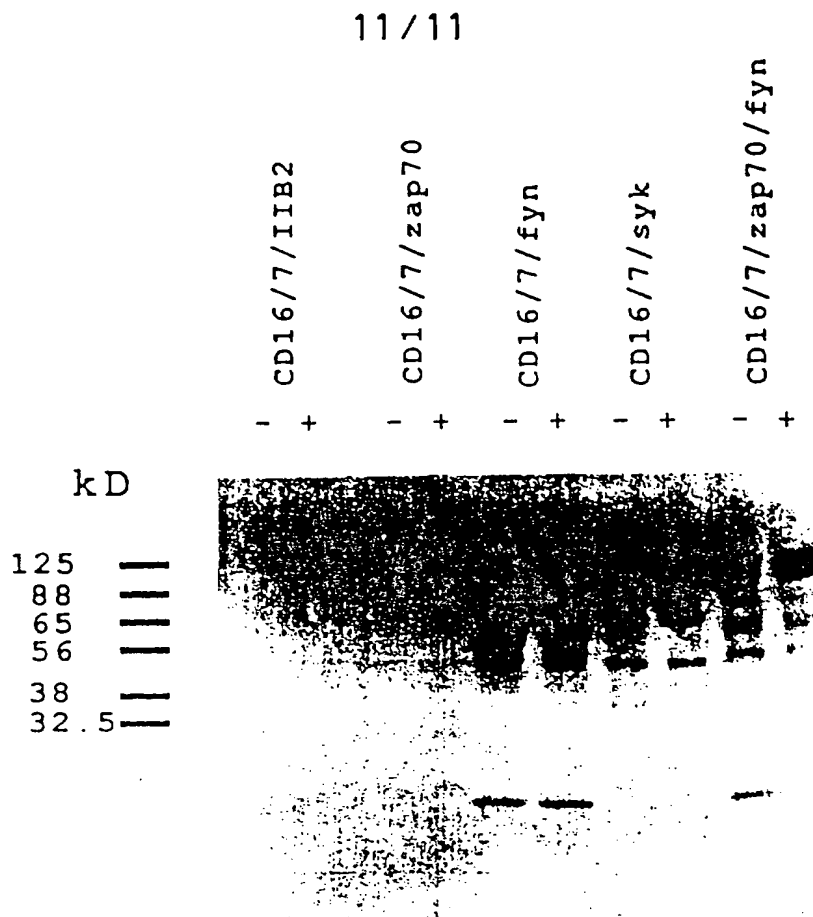
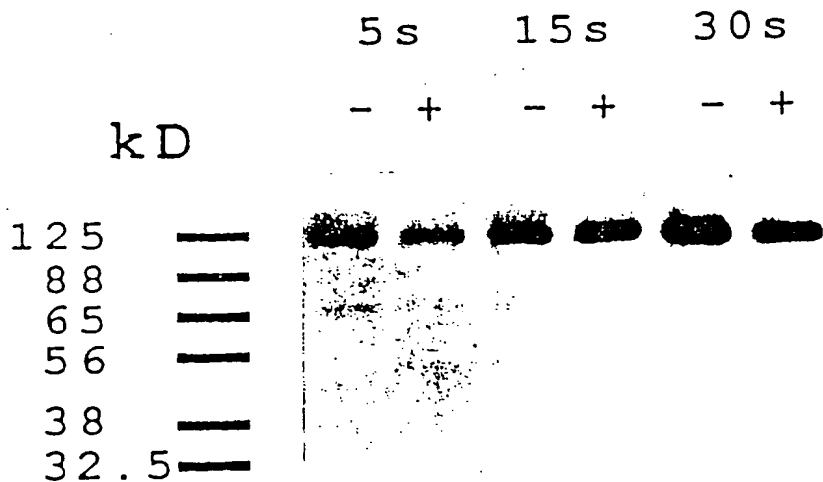


FIG. 8



CD16/7/syk  
**FIG. 10A**



**FIG. 10B**

## INTERNATIONAL SEARCH REPORT

 International application No.  
PCT/US96/01001

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C12N 5/00, 15/00, 15/63, 15/79; A61K 48/00

US CL : Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/93.1, 93.2, 93.21; 435/6, 240.1, 240.2, 69.1, 320.1; 530/387.3, 387.7, 387.9, 388.35, 388.3; 536/23.1, 23.4

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

STN, BIOSIS, MEDLINE, EMBASE, CANCERLIT, CAPLUS, APS, WPI

search terms: tyrosine kinase, chimera, chimeric, cells, lymphocytes, extracellular, intracellular

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	WO, A, 92/10591 (CELL GENESYS, INC.) 25 June 1992, whole document, especially pages 23-31 and 35.	1, 2, 11-14, 16, 17, 26-28, 31-33, 35, 37-40 ----- 3-10, 15, 18-25, 29, 30, 34, 36
X, P ---- Y, P	US, A, 5,439,819 (LITTMAN) 08 August 1995, columns 4-8 and column 12.	1-4, 11, 12, 16-19, 25, 26, 30-40 ----- 5-10, 13-15, 20-24, 27, 28-30

☒ X

Further documents are listed in the continuation of Box C.

☐

See patent family annex.

* Special categories of cited documents:	* T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
* A	document defining the general state of the art which is not considered to be of particular relevance	* X	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
* E	earlier document published on or after the international filing date	* Y	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
* L	document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	* G	document member of the same patent family
* O	document referring to an oral disclosure, use, exhibition or other means		
* P	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

04 APRIL 1996

Date of mailing of the international search report

02 MAY 1996

 Name and mailing address of the ISA/US  
Commissioner of Patents and Trademarks  
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# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/01001

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,359,046 (CAPON ET AL.) 25 October 1994, whole document, especially columns 8, 11 and 13.	1, 2, 11-14, 16, 17, 26-28, 31-33, 35, 37-40 ----- 3-10, 15, 18-25, 29, 30, 34, 36
Y	Advances in Cancer Research, Volume 57, issued 1991, Bolen et al., "Expression and interactions of the Src family of Tyrosine Protein Kinases in T lymphocytes", pages 103-149, especially pages 105-112.	36
Y	Cell, Volume 71, issued 13 November 1992, Chan et al., "Zap-70: A 70 kd Protein-Tyrosine Kinase that associates with the TCR $\zeta$ chain", pages 649-662, see entire document.	36
Y	The Journal of Biological Chemistry, Volume 266, Number 24, issued 25 August 1991, Taniguchi et al., "Molecular cloning of a porcine gene <i>syk</i> that encodes a 72-kDa Protein-Tyrosine Kinase showing high susceptibility to proteolysis", pages 15790-15796, especially page 15795.	3-10, 18-25, 36

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/01001

## A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

424/93.1, 93.2, 93.21; 435/6, 240.1, 320.1; 530/387.3, 387.7, 387.9, 388.35; 536/23.1, 23.4